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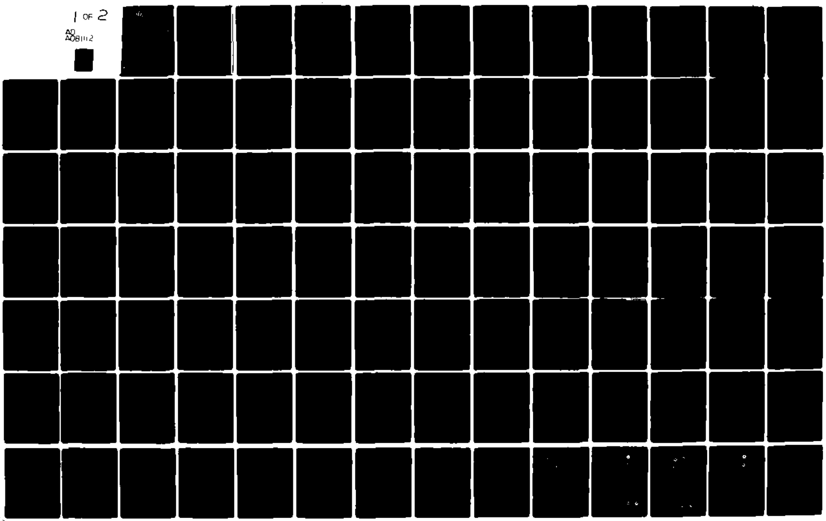

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FEASIBILITY OF FIELD TEST KITS FOR ASSESSING IN-SERVICE CONDITION OF ARMY ENGINE OILS

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INTERIM REPORT
AFLRL No. 117

by

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The Army has long needed portable test kit(s) to determine in-service condition of crankcase lubricants and power train lubricants. The obvious benefits of using field test kits to establish in-service lubricant quality include elevated equipment readiness and reduction in maintenance costs. MERADCOM/AFLRL initiated an R&D effort in December 1976 to develop a suitable mobile test kit, initially for crankcase lubricants. Several

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20. ABSTRACT

commercially available portable test kits were obtained and evaluated against standard ASTM laboratory test procedures which are normally employed to determine used-lubricant condemning limits. Some of the field test procedures were modified as required to enhance their utility or correlation potential. Source of the used lubricants included: laboratory diesel engines operating in fuels and lubricants R&D programs at AFLRL; M60 pilot fleet test vehicles at Ft. Carson, Co; administrative fleet vehicles at Letterkenny Army Depot, PA and Ft. Sam Houston, TX; and two privately owned vehicles at AFLRL. In conjunction with this current development effort, an assessment was made of Army fields test kit evaluation efforts conducted in the 1960's.

Results show that field test-kit improvements are required for viscosity and acidity determinations; and these two tests combined with portable dielectric constant measurements would have good potential to serve the Army needs. Overall results show that no single mobile test kit is available that will independently meet the Army's needs. Recommendations for additional evaluations and improvements are advanced.

FOREWORD

The work reported herein was conducted at the U.S. Army Fuels and Lubricants Research Laboratory (AFLRL), Southwest Research Institute, San Antonio, Texas, under Contracts DAAG53-76-C-0003 and DAAK70-78-C-0001. The work was funded by the U.S. Army Mobility Equipment Research and Development Command (MERADCOM), Ft. Belvoir, VA. Contracting Officer's representative was Mr. F.W. Schaekel, Fuels and Lubricants Division, Energy and Water Resources Laboratory (DRDME-GL).

ACKNOWLEDGMENTS

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I. INTRODUCTION AND BACKGROUND

A. Army Lubricating Oil Analysis

State-of-the-art lubricant analysis procedures are routinely applied in the research laboratory for both new and used lubricants. In a reasonable length of time (i.e., within three days), laboratory technicians and analytical chemists can identify a lubricant, establish its condition, and determine if an oil change should be made. Although such characterization is often accomplished for a small number of oil samples, it is impractical and cost prohibitive to subject every Army vehicle oil sample to such an extensive analysis. In the field, the user wants an answer, usually within a few minutes or hours, to the following questions: (1) what is the condition of his mechanical component (i.e., engine, transmission, or final drive), (2) what is the condition of the lubricant in the mechanical component, (3) how can premature oil changes be reduced or eliminated, and (4) how can equipment failures/removals be reduced or eliminated? The Army's Oil Analysis Program (AOAP) has aided in answering the first and fourth questions. However, in answering Questions two and three, no acceptable method of rapidly establishing inservice lubricant condition has been found by which maintenance personnel can schedule oil changes based on immediate determination of lubricant condition, rather than on the traditional time/mileage criteria.

In most cases, lubricant condition is best determined by comparing a specimen of used oil taken from the equipment to a sample of the new oil. However, this comparison is complicated by differences in oil chemistry, since the Army's engine oil specifications are based on lubricant performance rather than lubricant composition. For example, accidental use of wrong specification products or the mixing of several different supplier's products and viscosity grades qualified under the same specification in many engines makes identification of the specific lubricant(s) extremely difficult and time consuming. Unlike a commercial fleet operation in which one specific lubricant (i.e., quality level and brand name) can be specified for certain vehicles/operations, the Army is compelled to buy according to specification for a given lubricant, resulting in various different suppliers. As a result,

at any point in time, Army personnel may use more than one lubricant composition in a particular engine or class of engine. Since the identity of the resultant oil mixture is not known, a rapid comparison with the new oil is quite difficult. This identity depends on the percentage of each oil present in the engine and the specific composition of each product. Therefore, if a used oil cannot be compared with a known new oil, determination of the used oil's condition and its drain criteria must be based on general lubricant degradation experience and on specific lubrication technology.

B. Army Lubricant Formulation Technology

Until the early 1960's, the U.S. Army procured and used relatively simple lubricants in comparison with those materials being offered as a result of the modern lubricant formulation technology of the 1970's.[(1,2)*] Prior to the 1960's, it was common for the Army to purchase single-grade, conventionally formulated mineral oils of different quality levels, depending on the performance requirements of the equipment in which the lubricants were to be used. In the late 1960's, the Army recognized the benefits of using multiviscosity-grade engine oils and quickly adapted these oils[(3)] for noncombat-type vehicles (e.g., GSA Interagency motor pool sedans and pickup trucks; U.S. Postal Service trucks and sedans; and DOD commercial trucks and sedans). These multigrade oils, with high-molecular weight polymers added for high-temperature thickening purposes, resulted in a series of complex problems to the government due to the nature of the polymeric thickening material, generally referred to as a viscosity index improver. These viscosity index improvers undergo varying degrees of shear degradation in service and generally lose some or all of the viscosity-improvement capability they are intended to impart to the finished lubricant. From an analytical standpoint, these materials present problems of identification (i.e., polar and nonpolar blends) and separation because of the critical solubility of the polymeric improvers. It is particularly difficult to identify or separate if the lubricant is a used sample which possibly was mixed with another supplier's oil in the field.

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* Superscript numbers in parentheses refer to the list of references at the end of this report.

Lubricant formulation technology has continued to advance and to become more complicated since the mid-1960's, at which time the Army began buying synthetic-based arctic engine oils. The difficult requirements of low-temperature fluidity coupled with good high-temperature performance in modern high-output diesel engines necessitated the development[4,5] of a new arctic engine oil specification.[6] Although formulated with synthetic lubricants, the new arctic engine oil specification is still based on performance requirements rather than lubricant composition.

More recently, the 1973 Middle East oil embargo and the advent of so-called long-life or extended drain and no-drain synthetic crankcase lubricants[7-10] required the Army to intensify its chemical analysis research and development efforts. These intensified efforts have provided a basis for the characterization of the many different lubricants or combinations of lubricants used in fielded equipment and have helped provide a better understanding of the nature of today's complex lubricants.[11-15] It must be emphasized, however, that these are laboratory instrumental-analytical methods and are not currently applicable to rapid field usage.

C. Lubricant Test Kits and the Army's Experience

The concept of test kit usage to rapidly establish in-service/used-lubricant condition is not new to the Army. References 16 and 17 are two specifications (under U.S. Navy custody) that describe the performance requirements of such kits for rapid field assessment of used-lubricant condition. More recently, an Army Technical Bulletin[18] was issued to provide information and guidance pertaining to use of referenced test kits for the maintenance of proper engine lubrication conditions. Technical Bulletin TB-TC 15-17 evolved from the MIL-T-19467 (Ships) Oil Testing Kit which was presumably correlated with the USN MIL-L-9000-series diesel engine lubricants. These MIL-L-9000-series lubricating oils were and are formulated with an additive chemistry considerably different and less complex than the Army's MIL-L-2104C- or MIL-L-46152-type oils. The extreme difference in additive systems between the USN MIL-L-9000 series of lubricants and the Army's MIL-L-2104C/MIL-L-46152 lubricants adds to the already complex identification problem cited earlier.

The two Navy engine oil test kits were evaluated in conjunction with a U.S. Army/U.S. Navy facility administrative vehicle fleet test conducted at the Naval Ordnance Station, Indianhead, Maryland in 1968-1969.[19,20] Both test kits were evaluated by comparing results obtained with the kit system versus the ASTM standard tests on identical engine oil drain samples. Details of these oil test kit evaluations are given in References 19 and 20. It is worth noting that, in most instances, the results obtained from either of the two oil test kits did not correlate with the ASTM laboratory test methods. Also, in several instances, the two test kit results did not agree with each other in establishing unsatisfactory or acceptable lubricant condition.[21]

Development of a mobile/portable field oil-test kit which would apply to all types of engines, lubricants, and operating conditions is still required. A suitable field oil-test kit would result in: (1) improved vehicle/equipment readiness, (2) reduced routine maintenance time and costs, (3) reduced logistics volumes, and (4) reduced drain-oil disposition problems.

II. DETAILS OF TESTS

A. Mobile Test Kits

The initial phase of this program was to investigate the acceptability of currently available commercial mobile lubricant test kits, including the two Navy units discussed earlier.

The majority of these kits were procured as they became available or as their existence became known. All or parts of these kits were evaluated, and their operations are discussed in the following subparagraphs.

1. Oil Test Kit "A"

The literature with this kit states that the Spot Test in this kit provides an estimate of the percentage of carbon or solids per volume of fluid and is similar to the laboratory carbon residue test. A drop of used oil is placed on the spot-test paper and allowed to spread. The spot is then compared to a Tone-a-graf to record the total solids in the oil. This method also identifies excess water in the oil.

The kit's viscosity test compares the used oil with a sample of known viscosity (new oil). The viscometer consists of two parallel tubes, each containing a metal ball. One tube contains the new oil, and the other the used oil. The metal balls are lifted with a magnetic bar and then released. Their rates of fall are then observed. This test kit measures the difference in distance traveled for a falling (or rolling) ball over a 12-cm length at ambient temperature. Originally, the viscometer had areas marked "Good," "Fair," and "Poor" to indicate at which time the used oil should be changed. These markings have been replaced with a graduated scale for more accurate readings. Positive numbers mean the used oil is more viscous than the reference oil; negative numbers mean the test (used) oil is less viscous (i.e., fuel dilution or shear degraded) than the reference oil.

The acidity test in the kit makes use of a change in color of an indicator solution due to the pH of the oil. The test is performed by adding a solution to a vial which contains 1 cm^2 of used oil. The vial is then shaken vigorously. The solution then changes to either blue, green, or yellow, indicating the oil's condition to be good, mildly acidic, or dangerously acidic, respectively.

2. <u>Oil Test Kit "B"</u>

The Test Kit "B" is an Oilprint Analysis and is designed to indicate alkalinity, dispersancy, total contaminants, and cooling contaminants. Several of the other test kits (i.e., Kits Nos. A, D, F, and I) had a spot test as part of their kit. In all these tests, a drop of the used oil is placed on an absorption material, and the spot is compared to a gauge and the previous spot.

3. <u>Oil Test Kit "C"</u>

Test Kit "C" is used to semiquantitatively measure concentrations of contaminant metals in used oils in the 0- to 100-ppm range as well as the relative acidity or basicity of the oil. The apparatus consists of five tubes with different reagents to measure each specific contaminant of iron, tin, chromium, copper, as well as the pH (acid-base). Samples of a used oil are added to the tubes containing the reagents. The tube is then shaken and allowed to

set for the prescribed time. Afterwards, the color change is compared to the color chart for approximate contaminant/acidic/basic concentrations.

4. <u>Oil Test Kit "D"</u>

This kit, which conforms to MIL-T-19467 (Ships) and MIL-T-22493 (Wep), contains equipment for estimating fuel dilution, reaction (pH), and solids content of the used oils. The fuel-dilution test is performed by using a viscosity comparator. This device consists of two cone-shaped cups, each with an orifice in the bottom. The time necessary for the used-oil sample to flow from one cup is measured and compared to the flow time for the new oil, diluted with 5 percent of the engine fuel, in the other cup. If the used oil flows through in less time than the new oil mixture, the used oil has 5 percent or more dilution. The reaction (pH) test is performed by filling a vial to a prescribed level with a reaction indicator. The used oil is then added, the vial is shaken vigorously and allowed to set. The color of the liquid in the bottom is then compared with the reaction chart. If the color is blue, the pH is 6 or more; blue-green, a pH of 4.5; and yellow, a pH of 3.8. In the test for solid contaminants, one drop of used oil is placed on a filter paper and allowed time for absorption. The spot is then compared with the furnished chart to indicate a satisfactory, borderline, or unsatisfactory oil condition. The test for solid contaminants corresponds to engine oils containing sufficient blowby carbon to increase their carbon residue by 0.3, 0.6, and 1.3, respectively.

5. <u>Oil Test Kit "E"</u>

This device, which essentially measures the capacitance of the oil film, requires a single test operation for evaluating the used-oil condition. After calibration, three or four drops of oil are placed in the oil well, and the result is read on the meter. A reading of 10 or above indicates an unsatisfactory oil condition.

6. <u>Oil Test Kit "F"</u>

This kit considers five important in-service crankcase oil characteristics: acidity, alkalinity reserve, detergent/dispersant action, contamination level, and viscosity change.

For a complete test series, two separate procedures are required. The first procedure measures the acidity/alkalinity of the oil sample and requires several drops of indicator solution to be placed in a disposable indicator vial. A cotton swab saturated with used oil is inserted into the vial and pumped up and down. A blue solution indicates the oil is good (nonacid, good alkalinity); green indicates fair (nonacid, acceptable alkalinity); and yellow indicates poor (acid or near acid, insufficient alkalinity).

In the second procedure, a drop of oil from the dipstick is placed on a test slide of filter paper. A change in viscosity is determined by measuring the time required for the drop of oil to be fully absorbed in the test slide and comparing that time to the "viscosity norm" that has been previously established for that particular oil/engine/temperature situation. An increase in absorption time of 25 percent indicates the oil is in normal condition; 50 percent indicates fair condition; and 100 percent indicates poor condition. A decrease in absorption time indicates that the oil may be diluted or sheared. The detergent/dispersancy action data are obtained from the same test slide by measuring the diameter of the oil spot at full absorption. A 1.91 cm (3/4-in.) diameter oil spot indicates good detergent action; 1.27 cm (1/2-in.) diameter indicates fair action; and 0.63 cm (1/4-in.) diameter indicates poor action. Dispersion is indicated by a relatively even pattern throughout the entire oil spot. The kit has an oil-spot analysis chart with examples of contamination to which the test slide can be compared (light, medium, and heavy, and good, fair, and poor dispersancy levels). Also water contamination can be determined from the test slide.

7. <u>Oil Test Kit "G"</u>

This test detects, measures, and indicates the total effect of contamination on the dielectric constant of oil. This analysis is performed by first cal-

ibrating the tester with the new oil; then several drops of oil from the dipstick are added to the sensor cavity. The deviation meter is then read by switching to the proper range. Range one is used for mineral-based lubricants and a reading of less than 4.0 is the suggested safe zone. Range two is used for synthetic lubricants and a reading of less than 6.0 is the suggested safe zone.

8. Oil Test Kit "H"

This kit is a new version of Kit G and is more sensitive, uses a smaller sample, and does not use the dual range switch. The analysis is performed the same way. A reading less than 4.0 is the suggested rejecting threshold for mineral-base lubricants, while a reading less than 8.0 is the suggested condemning limit for synthetic oils.

9. Oil Test Kit "I"

The oil-change gauge consists of a block of transparent plastic with a groove [0.63 cm (1/4 in. wide) and 2.86 cm (1-1/8 in.) long] cut into the surface. This groove decreases in depth from 15 mils at the upper edge to zero at the bottom. Beneath the groove are four brown lines spaced 11 mm apart and numbered 2, 3, 4, and 5. When the groove is filled with oil, these lines represent oil film thicknesses of 2 = 15 mils; 3 = 12 mils; 4 = 9 mils; and 5 = 6 mils. The terminal extremes of the groove 0 and 20 mils are not used in the test. The brown color of the line is about the same color as the color of a thermally deteriorated and foreign particle contaminated oil. When line 5 is not visible through the oil film, the oil is sufficiently contaminated to be changed.

10. Oil Test Kit "J"

This kit evaluates the following used-oil properties: viscosity comparision, total acid number, blotter spot test, and insolubles. The viscometer consists of two parallel tubes, each containing a metal ball. One tube contains an oil of known viscosity and the other tube contains the test oil, both at ambient temperature. The unknown sample is related to the known sample by the rela-

tive rate of fall of each ball, and the viscosity rating is taken from a conversion table provided with the viscometer. Total acid number is determined by a smaller version of the ASTM D 974 standard test. In this test, the amount of materials used are reduced by a factor of 10. In addition, the oil sample is measured by volume (rather than weight), adjusted to approximate weight by a standard gravity correction factor. Blotter spot tests are used to determine the amount of dirt present and the dispersance that is left. The insolubles test involves filtering 1 ml of used oil through a 0.5-micron filter paper. After the filter is washed with naphtha, the color and density of the oil stain are visually matched to standards previously obtained by filtering used oils containing known amounts of C_5 and C_6 insolubles. This test has given results within the reproducibility limits of the ASTM D 893 method.

A summary of the operations performed on the various test kits can be seen in Table 1. In addition, a summary of the operations evaluated using these kits can be seen in Table 2.

B. Laboratory Engine Tests

For this program, 17 AFLRL laboratory engine tests were monitored using the conventional ASTM methods and various mobile oil-test kits. These tests were performed in conjunction with other programs to minimize the costs. The test data are shown in Table 3. The lubricants used included: one MIL-L-21260B Type 1, two candidate multiviscosity MIL-L-2104C, two MIL-L-2104C, one Reference Diesel Oil, one MIL-L-46152, three REO-191, one candidate MIL-L-46167, two MIL-L-46167, and four REO-203. Of these 17 tests, four tests were run in the Detroit Diesel (DD) Allison Model 3-53 engine using the 120-hour Steady-State Screening Test and three were conducted using the DD Model 6V53T engine according to the 100-hour Arctic Engine Oil Test (Method 354). In addition, ten tests were run using the DD Model 3-53 engine according to the 210-hour Wheeled-Vehicle Test cycle. Of these 17 tests, four had lubricant/mechanical problems which were predicted by the ASTM methods and the mobile oil-test kits.

TABLE 1. SUMMARY OF OPERATIONS PERFORMED BY TEST KITS

Operations	A	B	C	D	E	F	G	H	I	J
Visc. Measure.	x					x				x
Solid Content	x	x		x		x			x	x
Acidity/pH	x		x	x		x				x
Wear Metals			x							
Fuel Dilution				x						
Dielectric Const.					x		x	x		

TABLE 2. SUMMARY OF OPERATIONS EVALUATED

Operations	A	B	C	D	E	F	G	H	I	J
Visc. Measure.	x					x				
Solid Content	x	x		x		x			x	
Acidity/pH	x		x	x		x				x
Wear Metals			x							
Fuel Dilution				x						
Dielectric Const.					x		x	x		

TABLE 3. ENGINES, TYPE TEST, AND LUBRICANTS USED IN LABORATORY ENGINE TESTS

Engine Test	Test Cycle	Lubricant Code	Lubricant Description
1	W-V*	AL-6212-L	REO-203 Grade 30
2	W-V	AL-6212-L	REO-203 Grade 30
3	S-S**	AL-6409-L	MIL-L-2104C OE/HDO-10
4+	S-S	AL-6211-L	REO-191 Grade 30
5	W-V	AL-7062-L	REO-203 Grade 30
6	W-V	AL-6942-L	MIL-L-2104C Candidate Multigrade (Synthetic) 10W-30
7+	S-S	AL-6211-L	REO-191 Grade 30
8	354***	AL-7022-L	MIL-L-46167 OEA Candidate
9	W-V	AL-7219-L	REO-203 Grade 30
10+	354	AL-6214-L	REO-191 MIL-L-2104B CCL-L-694 Grade 10
11	W-V	AL-7135-L	MIL-L-2104C 10W/Multigrade Candidate (Synthetic)
12	354	AL-7283-L	MIL-L-46167 (OEA)
13	W-V	AL-7287-L	MIL-L-2104C OE/HDO-30
14	S-S	AL-6711-L	MIL-L-46152 10W/30
15	W-V	AL-7326-L	MIL-L-21260B Type 1
16	W-V	AL-6950-L	Ref Diesel Engine Oil (UK ER-5)
17	W-V	AL-6739-L	MIL-L-46167 OEA

* 3-53 W-V = Detroit Diesel Allison Division Model 3-53 engine, 210-Hour Wheeled-Vehicle Test Cycle.

** 3-53 S-S = Detroit Diesel Allison Division Model 3-53 engine, 120-Hour, Steady-State Screening Test.

*** 6V53T 354= Detroit Diesel Allison Division Model 6V53T engine, 100-Hour Arctic Engine Oil Test (Method 354, FTM Std 791B)

\+ = Engine failed before end of test.

C. Field Tests

Field tests were performed at Letterkenny Army Depot, PA; Ft. Carson, CO; Ft. Sam Houston, TX; and the U.S. Army Fuels and Lubricants Research Laboratory at San Antonio, TX. With the exception of the test at the Army Fuels and Lubricants Research Laboratory, all of the tests were also performed in conjunction with other programs to minimize the costs. Table 4 lists the vehicles and lubricants used during the field tests.

For this program, four vehicles were selected from the Letterkenny Army Depot Test Fleet for limited testing. This test fleet has been involved for 2 years in an "extended-drain" oil evaluation program to determine the feasibility of extending the life of crankcase lubricants. The vehicles used four distinct MIL-L-46152-qualified products--two mineral- and two synthetic-base--in four separate fleets and were operated under normal military operating conditions throughout the test. Monthly oil samples were taken from the test vehicles and monitored with some of the mobile oil-test kits.

Some limited testing was also performed on eight M60 tanks at Ft. Carson, CO. These vehicles at Ft. Carson were being tested to determine the feasibility of using synthetic arctic engine oils in outside arctic-operated combat/tactical vehicles. For this program, one baseline tank used MIL-L-2104C OE/HDO-30 lubricant, while seven tanks used MIL-L-46167 OEA lubricant. Although these eight vehicles were to have been sampled monthly, samples were not received by the AFLRL each month. Also, considerable problems were experienced with intermixing of two different OEA-qualified products due to a shortage of the specific brand of test oil.

At Ft. Sam Houston, TX, the field test involved five sedans, two station wagons, and five pickups for a total of twelve vehicles. These tests were conducted in conjunction with a 1-year vehicular exhaust emissions monitoring program to determine the possible improvements in exhaust emissions, maintenance, and fuel economy which can be realized from the diagnostic application of exhaust emissions analyzers to military gasoline-powered vehicles. The test fleet was divided into a control group and a test group, and the vehicles were operated under normal military operating conditions throughout

TABLE 4. VEHICLES, ENGINES, AND LUBRICANTS USED DURING FIELD TESTS

Vehicle No.	Vehicle Type	Location*	Test Mileage	Lubricant	
291	1973 Chev Station Wagon	LAD	27,434	MIL-L-46152 Synthetic	10W/30
289	1973 Chev Station Wagon	LAD	23,753	MIL-L-46152 Synthetic	10W/40
891	1973 Checker Bus 12-passenger	LAD	23,351	MIL-L-46152 Mineral	10W/30
890	1969 Checker Bus 12-passenger	LAD	12,328	MIL-L-46152 Mineral	10W/30
A-29	1973 Chev Sedan	FSH	5,537	MIL-L-46152	Mixed**
A-40	1972 Ford Sedan	FSH	4,238	MIL-L-46152	Mixed
A-79	1972 Ford Sedan	FSH	3,822	MIL-L-46152	10W/30
A-102	1973 Chev Sedan	FSH	3,612	MIL-L-46152	Mixed
A-716	1977 AMC Sedan	FSH	2,713	MIL-L-46152	10W/30
E-502	1975 Ford Station Wagon	FSH	4,931	MIL-L-46152	10W/30
E-503	1975 Ford Station Wagon	FSH	8,353	MIL-L-46152	Mixed
G-13	1972 Chev Pickup	FSH	4,440	MIL-L-46152	10W/30
G-125	1972 Chev Pickup	FSH	2,874	MIL-L-46152	10W/30
G-429	1974 Chev Pickup	FSH	2,464	MIL-L-46152	10W/30
G-435	1974 Chev Pickup	FSH	3,315	MIL-L-46152	Mixed
G-437	1974 Chev Pickup	FSH	4,228	MIL-L-46152	10W/30
A-31	M60A1 Tank	FC	665	MIL-L-46167	5W/20
A-32	M60A1 Tank	FC	677	MIL-L-46167	5W/20
A-33	M60A1 Tank	FC	867	MIL-L-46167	5W/20
A-34	M60A1 Tank	FC	347	MIL-L-46167	5W/20
A-35	M60A1 Tank	FC	731	MIL-L-46167	5W/20
B-11	M60A1 Tank	FC	881	MIL-L-2104C	OE/HDO-30
HQ-67	M60A1 Tank	FC	540	MIL-L-46167	5W/20
HQ-68	M60A1 Tank	FC	436	MIL-L-46167	5W/20
1	1978 Honda Accord	AFLRL	24,000	MIL-L-2104C	OE/HDO-30
2	1978 Ford 4x4 Pickup	AFLRL	7,500	MIL-L-46152	OE-30

* FSH = Fort Sam Houston, TX
FC = Fort Carson, CO
AFLRL = Army Fuels and Lubricants Research Laboratory, San Antonio, TX
LAD = Letterkenny Army Depot, PA

** Mixed lubricant is MIL-L-46152 using a 10W/30, 20W/40, or Grade 30

the test. MIL-L-46152 lubricants were used during the test and drained at the normal service conditions.

The AFLRL field test was conducted using two privately owned vehicles, one 1978 Honda Accord and a 1978 Ford 4x4 pickup. These vehicles were driven in normal stop-and-go type operation in going to and from work, normal weekend driving, and some off-road operation by their owners. MIL-L-2104C and MIL-L-46152 lubricants were used in these vehicles. The lubricants were monitored on a regular basis with the ASTM methods and various mobile oil-test kits.

III. DISCUSSION OF RESULTS

The test kits were received over a period of several months: therefore, all kit testing did not start simultaneously. These various kits were evaluated by comparing the results obtained from these kits with the ASTM method test results on the same new or used engine oil samples taken from both laboratory and field tests. The majority of the kit testing was done with the Test Kit H (dielectric constant), Test Kit A (acidity and viscosity comparator), and Test Kit B.

A. Laboratory Engine Tests

For this program, 17 AFLRL laboratory engine tests were monitored using conventional ASTM methods and several mobile test kits. Some engines had used an old model of Test Kit G, but the majority were monitored with the new Test Kit H (dielectric constant) and Test Kit A (acidity and viscosity comparator). Test Kits H and A were compared with the new oil for each respective test.

The results of the 17 engine tests monitored were tabulated and are included in Appendix A. Of these 17 engine tests, three were run in the Detroit Diesel Allison Division Model 6V53T engine according to the 100-hour Arctic Engine Oil Test (Method 354). In addition, four tests were performed according to the 120-hour Steady-State Test in a Detroit Diesel Allison Division Model 3-53 engine. Using this same engine, ten other tests were performed according to the 210-hour Wheeled-Vehicle Test Cycle procedure. In these 17 engine tests, results showed that there was one borderline pass (Engine Test No. 3, Figure

1) and two failures (Engine Test No. 4, Figures 2 and 3 and Engine Test No. 7, Figures 4 and 5) in a DD 3-53 engine with the 120-hour Steady-State Screening Test. Figures 2 and 4 compare the results from D 445 viscosity and wear metal analysis to the results from Test Kits A and H in Figures 3 and 5. It can be seen from these figures that a problem occurred with engine and/or lubricant between the 90- and 105-hour period, with both kits indicating that an oil change was required. Another failure occurred at 54 hours using the 6V53T engine under the 100-hour Arctic Engine Oil Test (Method 354). Figure 6 compares the ASTM Used Oil Analysis with the results obtained with the Test Kit H and the Test Kit A in Figure 7.

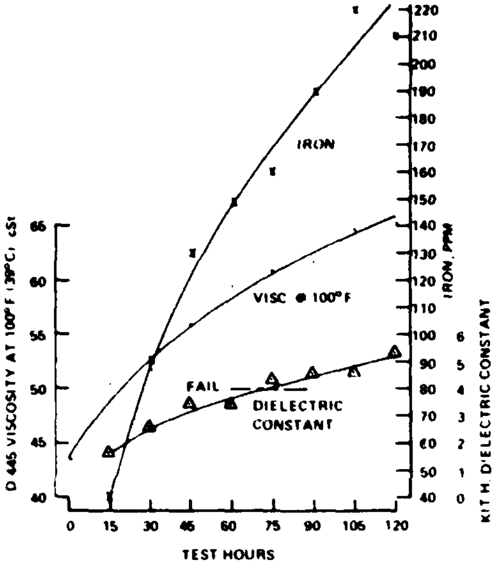

FIGURE 1. CORRELATION OF VISCOSITY, IRON AND DI-ELECTRIC CONSTANT OF TEST HOURS USING AL-6409-L ENGINE TEST NO. 3

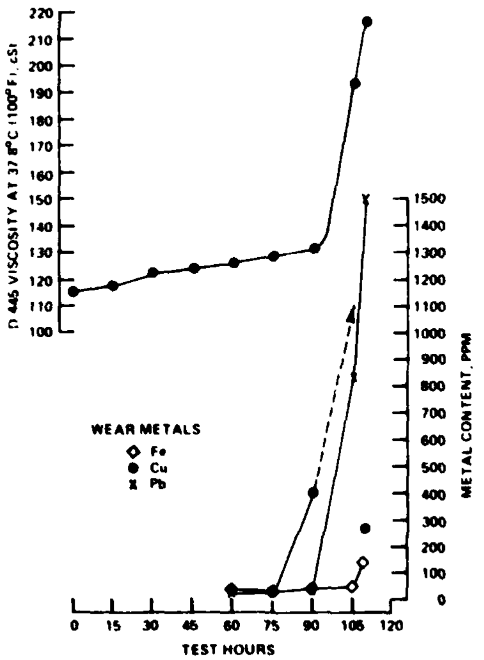

FIGURE 2. CORRELATION OF VISCOSITY AND WEAR METALS VS TEST HOURS USING AL-6211-L, ENGINE TEST NO. 4

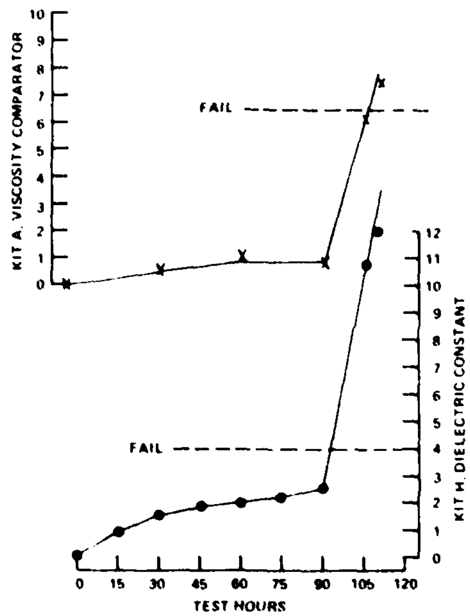

FIGURE 3. CORRELATION OF VISCOSITY COMPARATOR AND DIELECTRIC CONSTANT VS TEST HOURS USING AL-6211-L, ENGINE TEST NO. 4

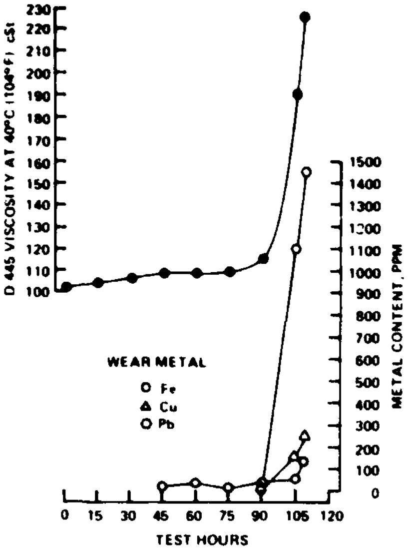

FIGURE 4. CORRELATION OF VISCOSITY AND WEAR METALS VS TEST HOURS USING AL-6211-L, ENGINE TEST NO. 7

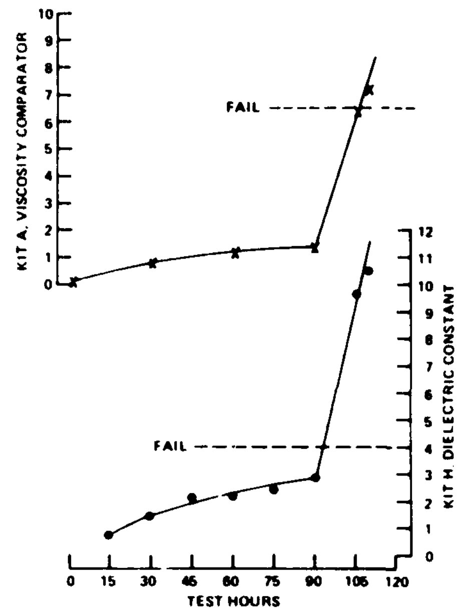

FIGURE 5. CORRELATION OF VISCOSITY COMPARATOR AND DIELECTRIC CONSTANT VS TEST HOURS USING AL-6211-L, ENGINE TEST NO. 7

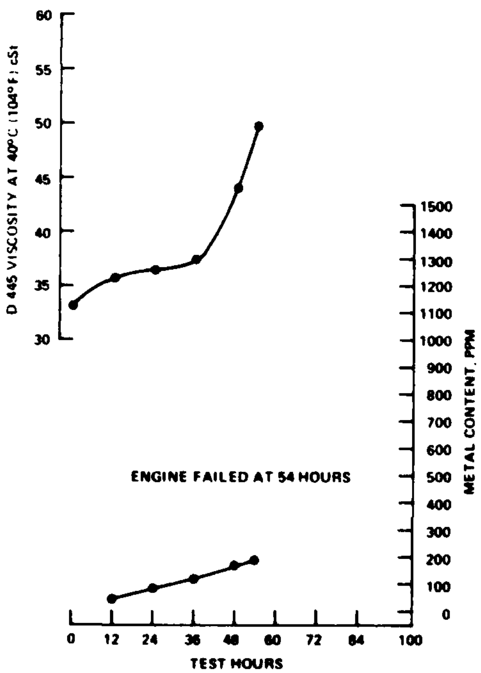

FIGURE 6. CORRELATION OF VISCOSITY AND IRON CONTENT VS TEST HOURS USING AL-6214-L, ENGINE TEST NO. 10

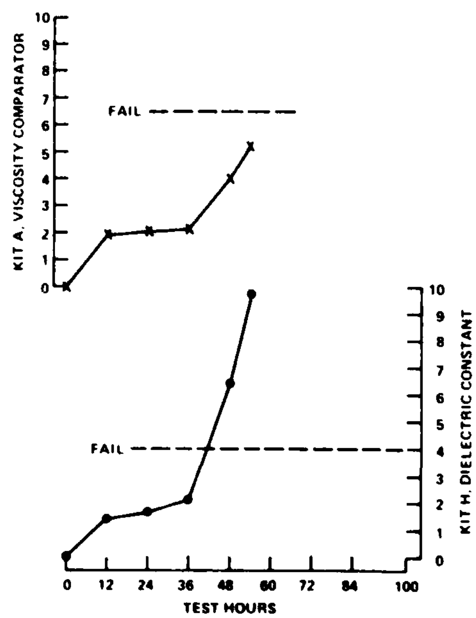

FIGURE 7. CORRELATION OF VISCOSITY COMPARATOR AND DIELECTRIC CONSTANT VS TEST HOURS USING AL-6214-L, ENGINE TEST NO. 10

All four of these engine test lubricant/ mechanical problems were predicted by the mobile oil test kits and the ASTM method tests. In fact, the mobile oil tests (dielectric constant, acidity, and viscosity) have fair correlation with the ASTM method test in relation to viscosity at 40°C, TAN, and wear metals as can be seen in Figures 8, 9, and 10 and in Appendix A, Tables A-2, A-3, A-6, and A-9. Although the data seem to indicate that the dielectric constant does not always correlate with the same particular test, it does appear to indicate overall oil condition. Even though overall correlation with Kit H and Kit A versus laboratory analysis was not achieved, each individual engine test and lubricants did. The lack of overall correlation is attributed to each test being compared to that test's new oil. A better overall correlation may have been achieved had a single reference oil been used.

Several tests were made with a CLR, one-cylinder engine which used methanol as fuel. A water/methanol/oil emulsion occurred. The water was detected with the Test Kit H (dielectric constant), but all values more than 1 percent went off-scale and could not be recorded.

B. Field Tests

The used oils from twenty-six vehicles were monitored with the mobile oil test kits and ASTM method tests. The vehicles were from the Letterkenny Army Depot, PA; Ft. Carson, CO; Ft. Sam Houston, TX; and the Army Fuels and Lubricants Research Laboratory in San Antonio, TX. The Letterkenny vehicles were tested first from samples starting in October 1975 and ending in April 1977.

The eight M60 tanks at Ft. Carson were monitored from September 1977 to September 1978, and twelve vehicles at Ft. Sam Houston were monitored from March 1978 to September 1978. The two privately owned vehicles at AFLRL were monitored from January 1978 to September 1978. Appendix B contains the results of the field test evaluations. Table 4 lists the vehicle numbers, description, location, and the lubricant used in field tests.

1. Letterkenny Army Depot Test Vehicles

For this program, four vehicles were selected from an extended-drain oil evaluation program fleet, each using a different MIL-L-46152 lubricant--two

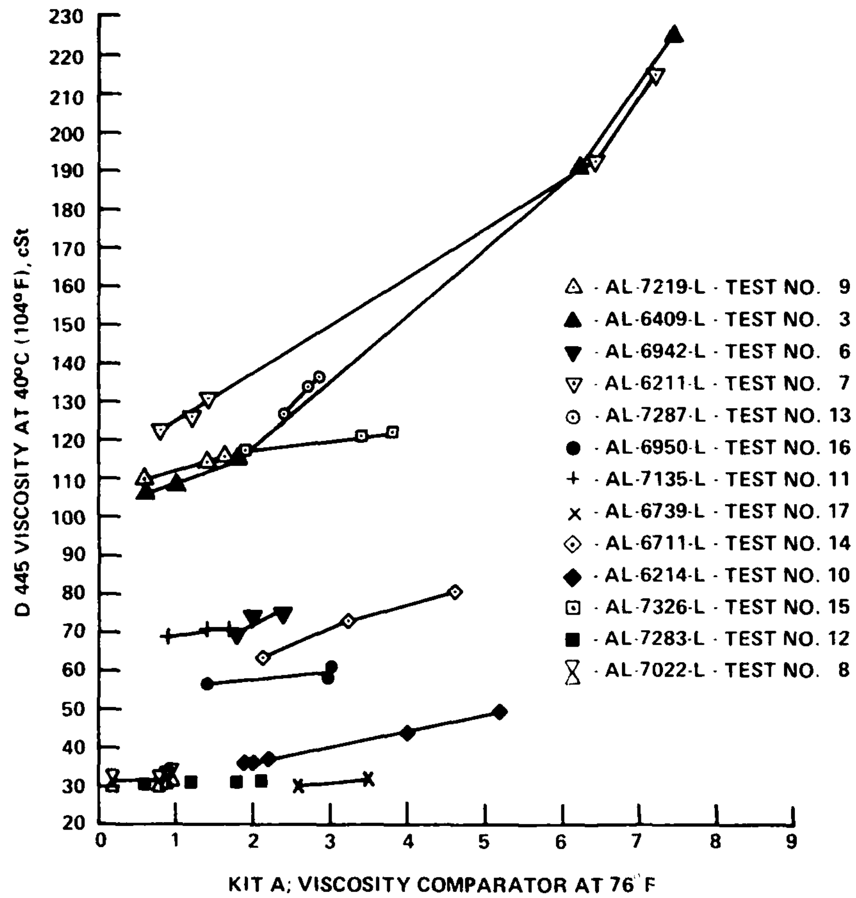

FIGURE 8. ASTM VISCOSITY VS VISCOSITY COMPARATOR USING LABORATORY ENGINE TEST LUBRICANTS

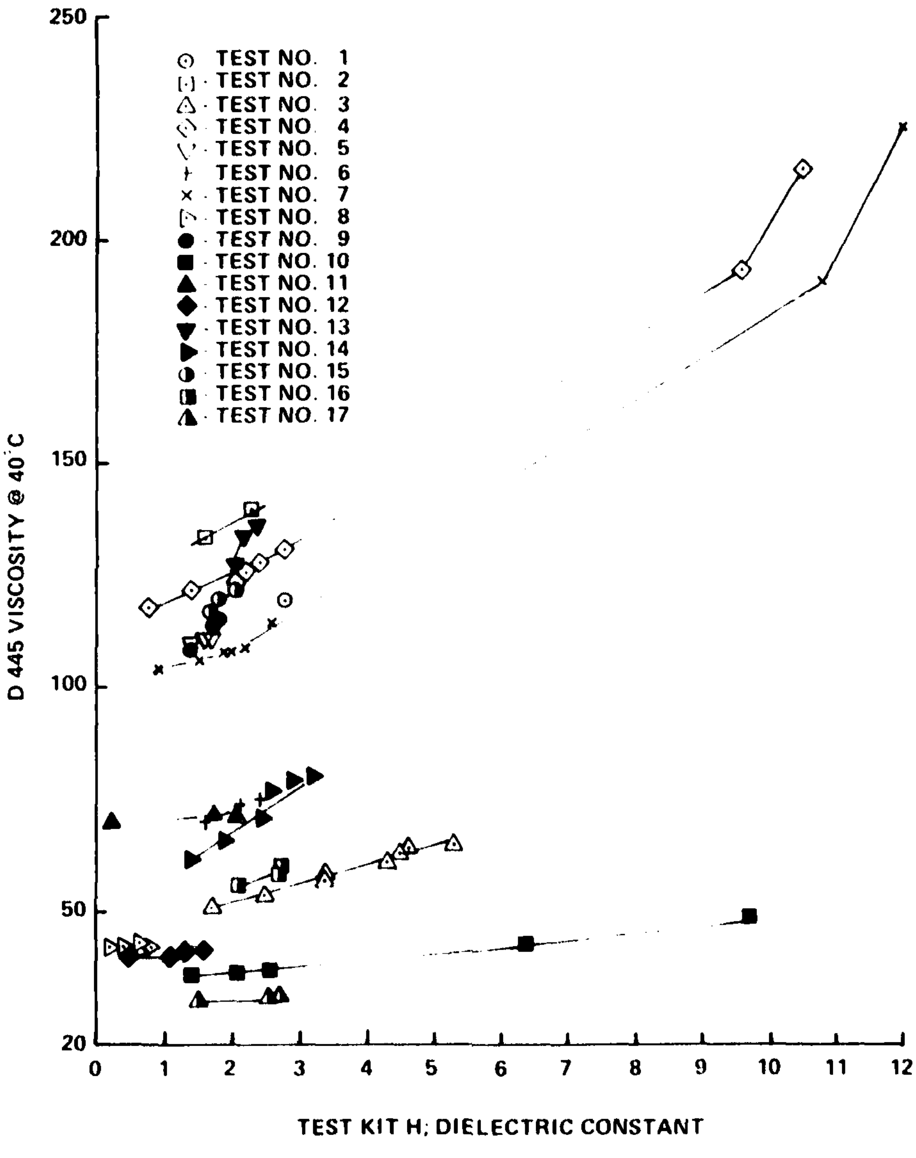

FIGURE 9. CORRELATION OF ASTM VISCOSITY VS KIT H USING LABORATORY ENGINE TEST LUBRICANTS

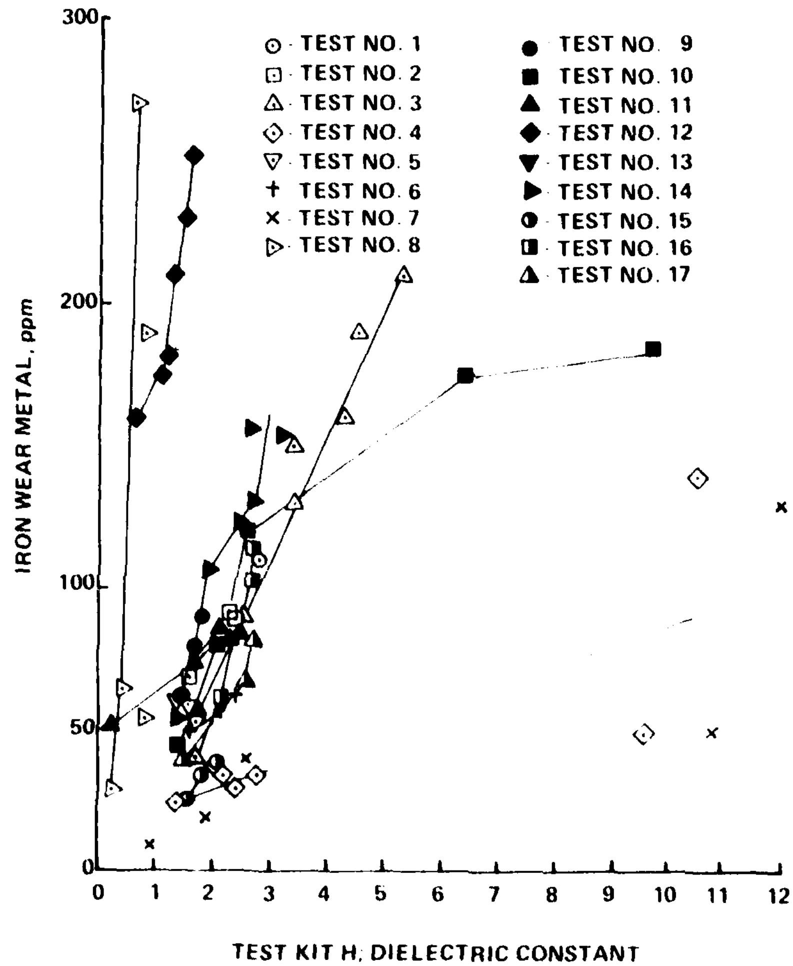

FIGURE 10. IRON WEAR VS KIT C USING LABORATORY ENGINE TEST LUBRICANTS

mineral-base oils and two synthetic oils. These four vehicles were part of a fleet which was on a 2-year extended-drain oil evaluation program(22) and were using D 445 viscosity at 100°F (40°C), the Test Kit B, and occasional viscosities at 210°F (100°C) and total acid number (TAN) as tests for monitoring the lubricants. The other mobile oil test kit used was the Kit G.

The guidelines for oil-change criteria for the fleet were:

	Fleets							
	Synthetic		Mineral		Synthetic		Mineral	
Estimated	AL-6088-L		AL-5936-L		AL-5941-L		AL-6095-L	
Guidelines	Min	Max	Min	Max	Min	Max	Min	Max
Viscosity at 100°F (40°C), cSt	40	110	45	110	60	130	50	120
TAN, max		7.0		7.0		7.0		7.0

The vehicle using AL-5936-L (mineral base) lubricant was a 1969 Checker 12-passenger bus (Vehicle No. 890) and only had a filter change between 5 October 1975 and 2 September 1976. The blotter spot test and the Test Kit G indicated that the oil should possibly have had a filter or oil change as early as 3 June 1976. The filter change was definitely required when the procedure was performed because of water in the lubricants as indicated in Table B-1 and Figure B-1 of Appendix B. Vehicle No. 891 using the other mineral-base lubricant AL-6095-L was also a 1969 Checker 12-passenger bus. This vehicle had an oil change between 4 December 1975 and 1 January 1976 because of high lubricant viscosity and again between 1 November 1976 and 8 December 1976. This change was also made due to high lubricant viscosity and possible high acid number. In addition, it appears from the viscosity at 100°F (40°C), blotter spot test and Test Kit G that the vehicle needed an oil or filter change in August or September 1976 and on 6 April 1977 as indicated in Table B-2 and Figure B-2 of Appendix B.

The vehicle using AL-5941-L synthetic lubricant was a 1973 Chevrolet station wagon, which needed an oil change between 4 November 1976 and 7 December 1976 because of high viscosity and high acid number. The blotter spot test and the Test Kit G, along with viscosity, indicate that the vehicle should have had an oil or filter change 2 June 1976 (see Table B-3 and Figure B-3 of Appendix B). The vehicle using the other synthetic lubricant AL-6088-L was also a 1973

Chevrolet station wagon and had an oil change due to high viscosity and high acid number between 11 March 1977 and 8 April 1977. Table B-4 and Figure B-4 in Appendix B show that viscosity, TAN, blotter spot, and Test Kit G results indicate that the engine oil should have been changed on 3 November 1976.

The data collected appear to indicate that the kits used were able to determine engine oil quality well enough to indicate oil or filter change.

2. Ft. Carson Test Vehicles

The test vehicles at Ft. Carson, CO included eight M60 tanks. Of these vehicles, one used MIL-L-2104C OE/HDO-30 and seven used MIL-L-46167 (5W/20 Arctic Oil). These vehicles were monitored from September 1977 to January 1978, using the new Test Kit H (dielectric constant), Test Kit A acidity, and viscosity comparator tests (See Tables B-5 through B-12 of Appendix B).

The new Test Kit H used only one expanded range to cover both mineral and synthetic lubricants, which made it easier to operate, and has a suggested safe range of 4.0 or below for mineral-base lubricants and 8.0 or below for synthetic lubricants. Figure 11 shows a good correlation of ASTM D 445 viscosity at 40°C with the viscosity comparator kit results when using the synthetic lubricant. However, insufficient points are available to correlate the viscosity of the OE/HDO-30 lubricant with the viscosity comparator kit results. It appears the used oil sample never had a sufficiently high TAN to achieve a color change in the acidity kit. As shown in Tables B-5 through B-7 of Appendix B, the Test Kit H did quite well with Tanks Nos. B-11, HQ-67, and HQ-68. However, the Test Kit H experienced problems with Tanks Nos. A-31, A-32, A-33, A-34, and A-35 when all readings were negative, indicating excessive fuel dilution. These results are shown in Tables B-8 through B-12 of Appendix B. In February, it was learned that two MIL-L-46167 5W/20 lubricants had been mixed together, thereby resulting in

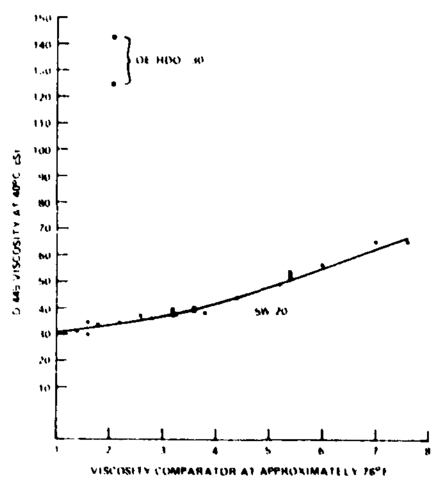

FIGURE 11. ASTM VISCOSITY VS VISCOSITY COMPARATOR USING M60 TANKS AT FT. CARSON

negative readings because the higher reading AL-6739-L was used as reference and when lower reading AL-5140-L was added it diluted and lowered the Kit G reading. The differences between the two MIL-L-46167 lubricants are listed below:

	MIL-L-46167	
Properties	AL-6739-L	AL-5140-L
Viscosity, cSt		
at 100°F (37.8°C)	29.3	35.1
at 210°F (98.9°C)	6.1	6.5
Viscosity Index	180	153
TAN	0.22	2.04
TBN	7.8	8.04
Flash Point, °C	244	227
Test Kit G	+12.0	0

Even though the Test Kit H did not give usable readings, it did indicate an aberration with the lubricant or that the wrong lubricant was used. This is further illustrated in Table 5 where Test Kit H readings are presented for four different synthetic lubricants used in the Letterkenny Army Depot and Ft. Carson fleet tests. These oils are the first four shown in the table, and it is noted that the two diester products have significantly higher dielectric constant values than the other two products which are blends of diester and synthetic hydrocarbons (SHC). Therefore, indiscrimate use of the Test Kit H instrument without knowledge of the lubricant base stock composition could lead to serious error in used lubricant condition determinations.

3. Ft. Sam Houston Test Vehicles

As a result of the work performed with laboratory engines, Letterkenny Army Depot vehicles, and the M60 tanks at Ft. Carson, it appeared that the Test Kit H dielectric constant and the Test Kit A acidity and viscosity comparator tests kits should be used for the Ft. Sam Houston field test. These test kits did correlate quite well with ASTM test methods to evaluate the used engine oil quality in the laboratory engines and the Letterkenny vehicles.

Since Test Kit H correlates reasonably well with ASTM D 445 viscosity and engine wear metals as shown earlier, it was felt that this kit might even serve as a screening test. To evaluate this possibility, a number of MIL-

TABLE 5. EVALUATION OF LUBRICANTS USING TEST KIT H

AFLRL Code	Description	Kit H Reading (1)
	Synthetic Base	
AL-6739-L (Diester)	MIL-L-46167 OEA 5W/20	+12.0 (off-scale)
AL-5140-L (Diester/ SHC Blend)	MIL-L-46167 OEA 5W/20	8.4
AL-5941-L (Diester)	MIL-L-46152 10W/40	+12.0 (off-scale)
AL-6088-L (Diester/ SHC Blend)	MIL-L-46152 10W/30	8.9
	Mineral Base	
AL-6863-L	MIL-L-2104C OE/HDO-10	6.2
AL-6864-L	MIL-L-2104C OE/HDO-50	7.4
AL-6865-L	MIL-L-2104C OE/HDO-30	5.8
AL-6866-L	MIL-L-46152 10W/30	5.7
AL-6867-L	MIL-L-46152 10W/30	5.9
AL-6868-L	MIL-L-46152 10W/30	5.8
AL-6869-L	MIL-L-2104C OE/HDO-10	6.9
AL-6870-L	MIL-L-2104C OE/HDO-50*	6.2
AL-6871-L	MIL-L-46152 10W/30	6.3
AL-6872-L	MIL-L-2104C OE/HDO-30	9.0
AL-6873-L	MIL-L-2104C OE/HDO-50*	6.1
AL-6874-L	MIL-L-46152 20W/40	6.6
AL-6875-L	MIL-L-46152 10W/30	5.8
AL-6876-L	MIL-L-46152 20W/40	6.4
AL-6877-L	MIL-L-46152 20W/40	5.9
AL-6409-L	MIL-L-2104C OE/HDO-10 (Ref)	6.0
AL-6855-L	MIL-L-2104C OE/HDO-10	6.2
AL-7090-L	MIL-L-2104C OE/HDO-30	6.3
No Code	Composite of 18	6.5

* Lubricants were designated as 30 grade lubricant, but kit testing and ASTM procedures determined to be 50 grade.

(1) Instrument was calibrated to reading of 6.0 with reference lubricant AL-6409-L.

L-2104C and MIL-L-46152 lubricants were tested with the Test Kit H. The kit was calibrated to read 6.0 with AL-6409-L serving as the baseline lubricant. Of 18 mineral-based lubricants evaluated, 16 ranged from 5.7 to 6.9. The results of these evaluations are shown in Table 5. Only two lubricants had extreme readings of 7.4 and 9.0, as can been seen in Table 5. Since this spread was not ideal, the lower reading lubricant, OE/HDO-10 AL-6409-L, was used so that the kit would err on the safe side, i.e., indicate a need for an oil change even though not needed, rather than not indicate a change when an oil change was needed. Then equal volumes of the 18 lubricants were blended and a reading of 6.5 was obtained. Also, this kit can detect water in the amount of 1 percent.

From March to September of 1978, a total of 64 samples was collected from the 12 vehicles in the program. Tables B-13 through B-24 of Appendix B include analyses of these samples. Of these samples, the Test Kit H indicated that eight (see Tables B-13, B-14, B-16, and B-25) needed an oil change. However, ASTM test procedures indicated that an oil change was not required for five of these samples (See Tables B-13 and B-16). The five lubricants that did not require an oil change according to the ASTM Method were a Grade 30 and probably had a higher dielectric constant, such as AL-6872-L in Table 5. As shown in Figure 12, four samples had a TAN of 5.5 to 6.0 with four above 6.0. Only one of the samples, for vehicle G-125, indicated that it needed changing because both TAN and TBN were unacceptable. This sample was also the only one for which the acidity test kit indicated a change. The viscosity comparator did not indicate any required oil changes, which agreed with the D 445 viscosity at 40°C. Figure 13 shows a good correlation between the D 445 viscosity at 40°C and the viscosity comparator.

During this program, it was also found that the viscosity comparator can differentiate among various viscosity grades. Used in this program were several viscosity grades of lubricants that the comparator was able to identify as shown in Figure 13. The procedure used to distinguish among the 52 10W/30 and 12 Grade 30 or 20W/40 lubricant samples involved a dual baseline lubricant system. With each of the oil samples, the OE/HDO-30 lubricant was used as a baseline in the viscosity comparator test. If the metal ball in the used sample reached the bottom of the tube before its counterpart in the

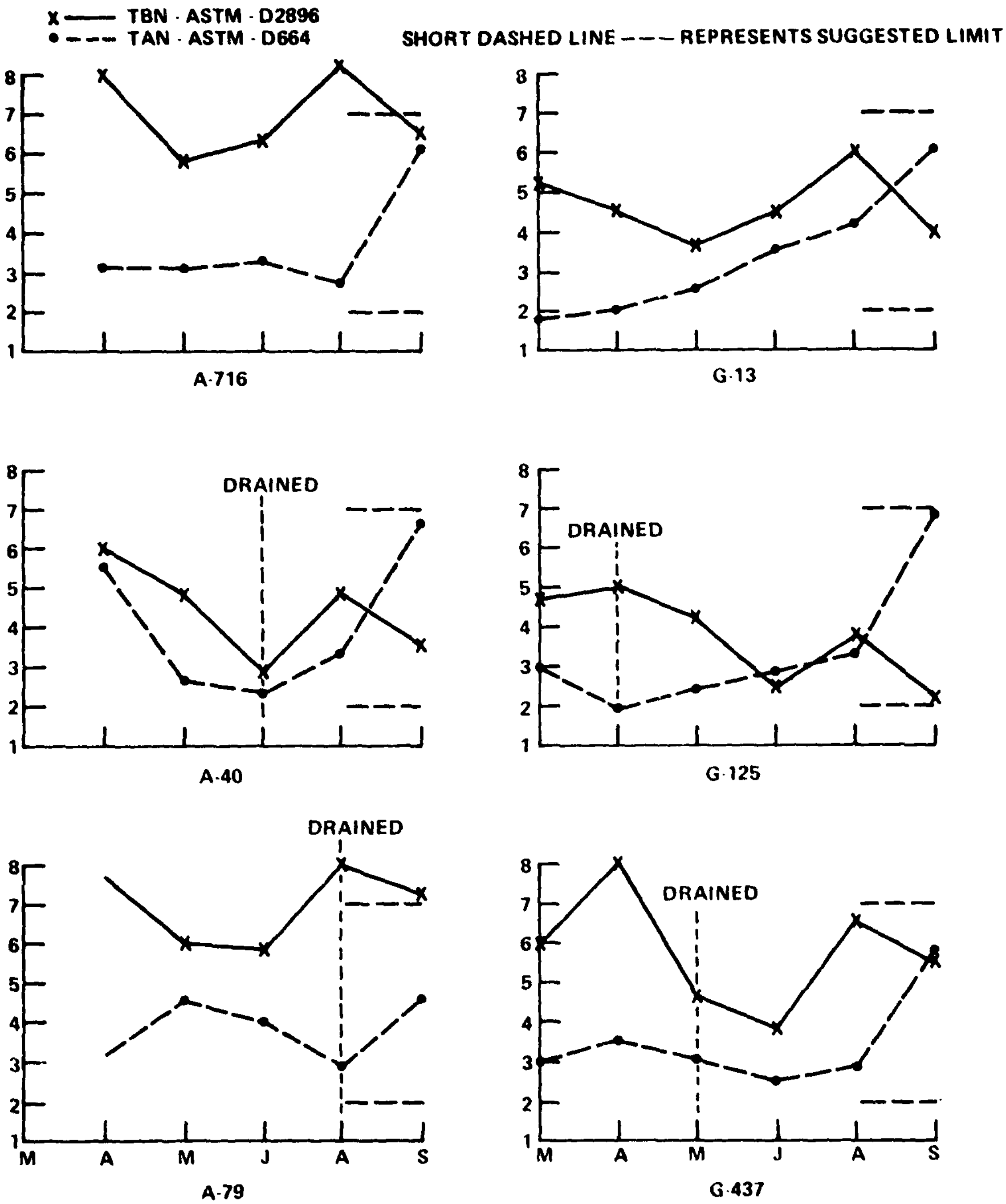

FIGURE 12. MONTHLY ACID/BASE NUMBER DETERMINATIONS FOR VARIOUS ADMINISTRATIVE VEHICLE ENGINES USING MIL-L-46152

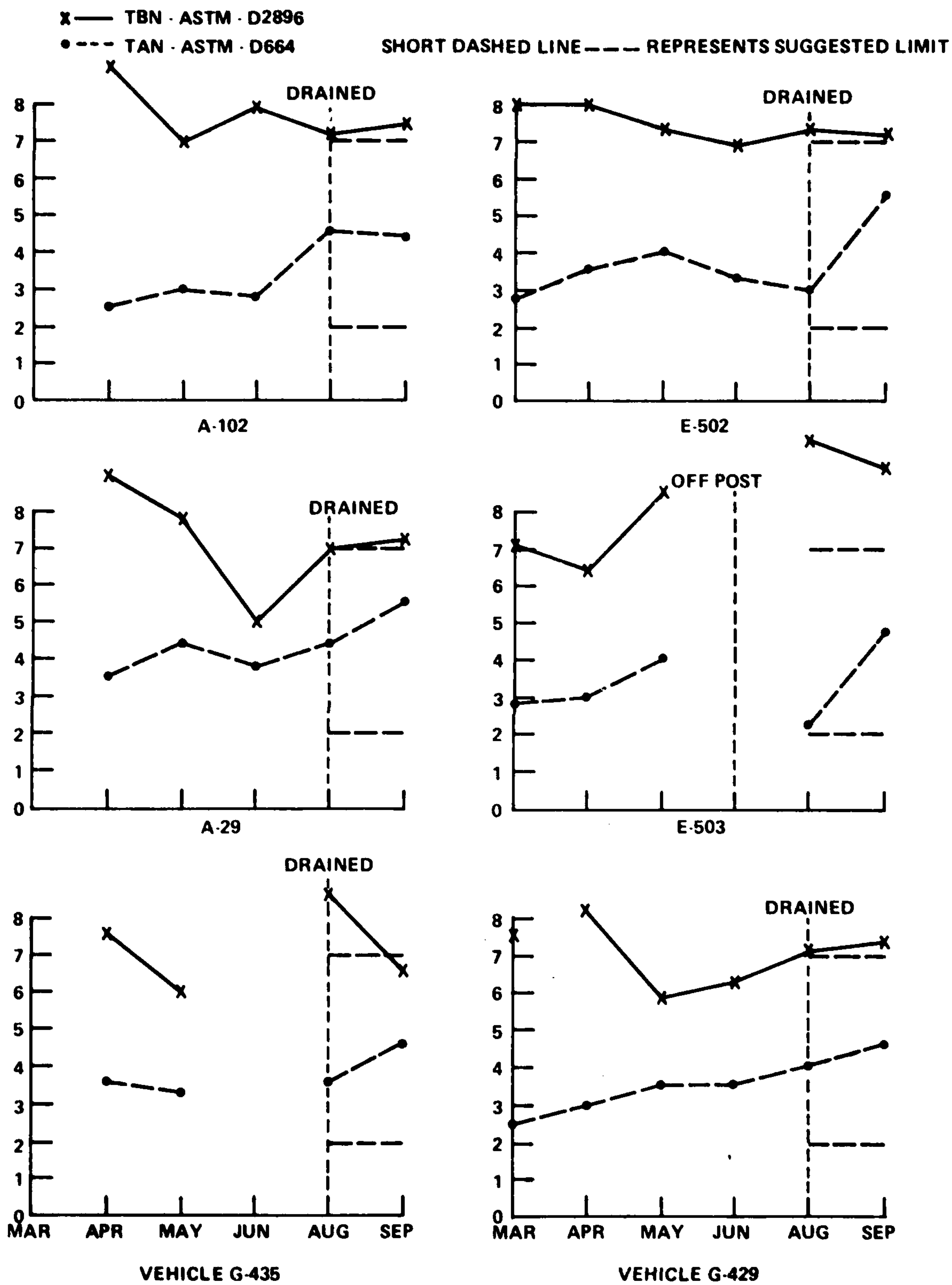

FIGURE 12. MONTHLY ACID/BASE NUMBER DETERMINATIONS FOR VARIOUS ADMINISTRATIVE VEHICLE ENGINES USING MIL-L-46152 (CONT'D)

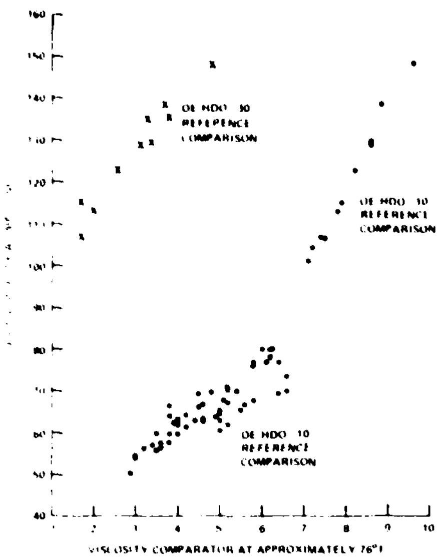

FIGURE 13. ASTM VISCOSITY VS VISCOSITY COMPARATOR FOR THE FT. SAM HOUSTON ADMINISTRATIVE VEHICLE ENGINES

reference oil, then a negative number would result. This negative number indicated either shear, dilution or a different grade lubricant. If this negative value occurred, the test was repeated, using the lighter weight OE/HDO-10 lubricant as the reference oil.

4. AFLRL Field Test Vehicles

The two vehicles involved in the AFLRL field tests were privately owned vehicles, a 1978 Honda Accord and a 1978 4x4 pickup truck. The Honda vehicle was driven for 12,000 miles with a MIL-L-2104 OE/HDO-30 lubricant. Oil samples were taken every 3,000 miles and were evaluated with various ASTM method tests as well as with the Test Kit H and Test Kit A. The resultant data are presented in Table B-25 of Appendix B. The lubricant samples taken from the vehicle appeared to be quite good for 12,000 miles. However, the pentane insolubles data are considered borderline. Both the Test Kit H and the ASTM insoluble tests indicate that the lubricant should be changed. The Ford 4x4 pickup truck was driven for 7,500 miles using a MIL-L-46152 grade 30 lubricant. Oil samples from the pickup were analyzed every 2,000 miles. Using the same ASTM procedures and mobile test kits discussed earlier, Table B-26 of Appendix B shows that the correlation among the kits is quite good. The viscosity comparator kit correlates with the D 445 viscosity at 40°C, while the Kit H (dielectric constant) indicates that the overall oil quality is bad. This finding agrees with the high iron content, high insolubles, and high acidity as seen in Figure 14. The correlation was not quite as good with the

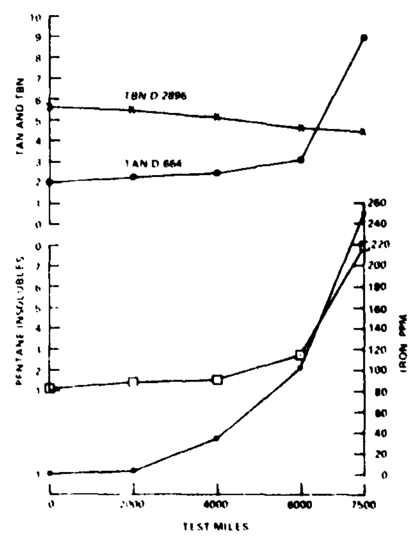

FIGURE 14. RESULTS FOR VARIOUS ASTM TESTS OF LUBRICANT SAMPLES FROM THE 4 X 4 PICKUP

acidity Kit A because it indicated yellow/green which is only borderline, while the TAN indicates a need for an oil change. Also, the correlation with lead was not good, but the high lead was probably due to the use of leaded premium and regular gasolines.

C. Limited Test Kit Evaluations

Several test kits were not evaluated in this program because of information which indicated that these kits would not work well with the various performance-qualified lubricants in the Army supply system. Also, after some preliminary testing, a decision was made to evaluate only the most promising kits because of the time and economic factors involved. This failure to evaluate some of the kits does not mean, however, that these kits could not possibly suit the Army's purpose with some modifications. The test kits which underwent limited evaluation are briefly discussed in the following subsections.

1. Absorption Viscosity

The Test Kit F was used as the directions indicated by obtaining a drop of used oil from the test engine's dipstick. However, the drop size from test to test varied too much and repeatable results could not be achieved. As a result, the test procedure was revised in an attempt to improve the repeatability. The adjustments in the procedure were (1) to use a small 0.36 in.-diameter wire and (2) to ensure that the same density size blotter paper is used in all tests. Figure 15 and Table 6 show that the repeatability was improved. Thus, the Kit F shows some promise as a test because no new lubricant is needed as a baseline for simultaneous testing. The acidity/alkalinity reserve test did not appear to correlate well with the D 664 TAN and D 2896 TBN as can be seen in Tables A-3 and A-7 of Appendix A. The oil spot test did provide fair results when determining the amount of solids present and the

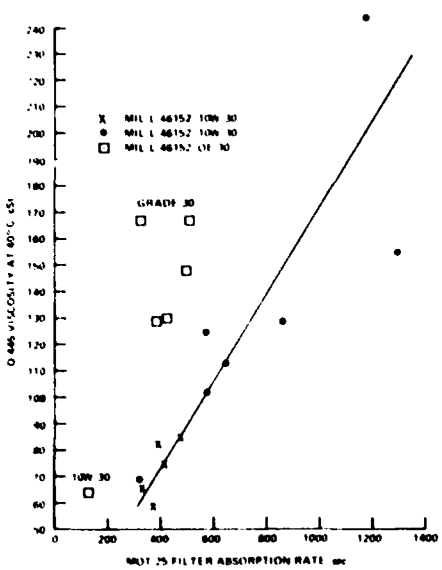

FIGURE 15. CORRELATION OF ASTM VISCOSITY VS ABSORPTION VISCOSITY RATE FOR VARIOUS MIL-L-46152 LUBRICANTS

TABLE 6. COMPARISON OF VISCOSITY TEST RESULTS

MIL-L-46152 10W/30 AL-5936-L		MIL-L-46152 10W/30 AL-6095-L		MIL-L-46152 Grade 30	
Filter Absorption Rate, s	ASTM D 445 cSt, 40°C	Filter Absorption Rate, s	ASTM D 445 cSt, 40°C	Filter Absorption Rate, s	ASTM D 445 cSt, 40°C
370	290.1	1298	124.8	381	128.7
370	58.5	319	69.2	493	148.4
408	74.3	560	124.8	320	166.9
389	83.2	631	112.8	504	166.9
468	85.2	851	129.0	422	129.7
*	290.1	1298	155.1	128	64.2
330	66.5	1164	244.5		
		582	102.6		

* Could not record a repeatable reading due to H_2O in lubricant.
NOTE: Drop size is critical to results of test.

TABLE 7. COMPARISON OF TOTAL ACID NUMBER TEST RESULTS

Vehicle G-13 MIL-L-46152		Vehicle G-125 MIL-L-46152	
ASTM D 664	FIELD KIT*	ASTM D 664	FIELD Kit
1.72	1.5	2.96	2.6
2.09	2.0	1.82	1.9
2.65	2.4	2.30	2.1
2.56	2.2	2.74	2.5
3.10	3.0	3.20	3.4
6.06	6.2	6.88	6.3

* Miniature D 974 - Colormetric

dispersancy left in the used oil. However, the spot test requires considerable experience to interpret and the blotter spots are hard to maintain.

2. Total Acid Number

This Test Kit J is a smaller version of the ASTM D 974 test and has shown good results when compared to the ASTM D 664 (TAN) test as can be seen in Table 7 and Figure 16. However, it was decided not to use this method because of established problems with its use. The color change is in the brownish-green area, a color which many people have difficulty seeing. In addition, the colors are usually very dark and require a lightbox to see the color change.

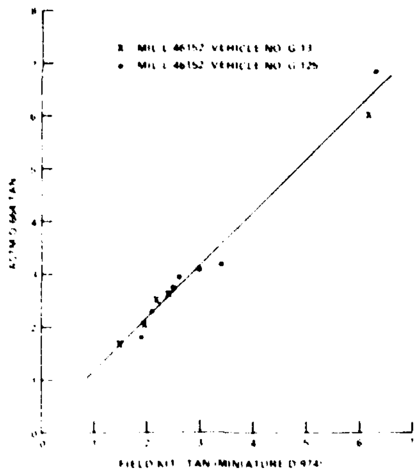

FIGURE 16. CORRELATION OF ASTM ACID NUMBER VS FIELD KIT ACID NUMBERS

3. Oil Test Kit C

This kit was used for testing a used synthetic 5W/20 and a used mineral base 10W/30 lubricant (see Table 8). It was difficult to match the actual color of reagent/used oil with the color chart. According to the kit manufacturer, the color concentrations on the chart are for components from an organo-metallic oil standard, but the used oil samples are wear particles and could possibly not respond in the same way as the standards.

TABLE 8. OIL TEST KIT C EVALUATION

Used Lubricant Description	Synthetic 5W/20		Mineral 10W/30	
AFLRL Code	AL-7386-L		AL-7409-L	
Test Method	AA*	KT-1	AA	KT-1
Metals, ppm				
Fe	103	50 100	86	50 100
Cu	6	10	5	10
Cr	0	50	5	50
Sn	14	10	12	10
Acid/Base, pH	8.0	6	7.2	6

* Atomic Absorption.

4. Oil Test Kit I

The oil change gauge should be sensitive to both the increase in color (darkness) and the accumulation of particulate matter, both of which contribute to the increase in optical density (opacity). This technique is limited to conventional petroleum oils formulated for spark-ignition engine service, and should not be used for diesel and/or synthetic motor oils possibly because the diesel oil contains soot. Also, a problem arose because the groove and the card backing on which the numbered lines are located for evaluation are not rigidly fastened together. As a result, the depth of oil film in the groove may vary from gauge to gauge. In the two examples in Table 9, the gauge did not accurately predict the oil changes on mineral- and synthetic-based lubricants.

TABLE 9. OIL TEST KIT I RESULTS

Sample Date	Total Miles	Miles/ Month	Visc at 40°C	Oil-Change Gauge*
Red Lubricant (AL-5889-L) MIL-L-46152, 10W/20				
New Oil Vis at 100°F = 68.5 cSt				
1-18-77	68,859	406	64.1	5+
3-10-77	69,890	1031	70.3	4+
4-08-77	70,024	134	73.2	5+
5-06-77	70,385	361	78.1	5+
6-10-77	71,579	1194	73.6	5+
Yellow Lubricant (AL-6095-L) MIL-L-46152, 10W/30				
New Oil Vis at 100°F = 77.2 cSt				
12-8-77	48,267	573	102.6	3
2-11-77	49,455	1188	131.2	4+
4-06-77	53,216	2088	236.1	5+
5-06-77	54,800	1584	224.3	5+
6-06-77	55,394	594	192.2	5+

* If line 5 is not visible through oil film, oil and filter should be changed. The plus sign means the number preceded was not visible and could not be read.

5. Assessment of Past Performance of Test Kit Analyzers

The Oil Test Kit D and Oil Test Kit E were not physically evaluated in the current program because earlier Army evaluations [19-21] revealed that these

kits would not work when used with a mixed variety of MIL-L-2104C and MIL-L-46152 products. A tabulated summary of these earlier results is shown in Appendix C.

In reviewing the tabulated results in Appendix C, the values obtained from the Kit D and Kit E techniques were compared against those results reported from the ASTM procedures with the latter being employed on a referee basis. Using the condemning use limits recommended by both manufacturers (namely, a 10.0 or above for the Kit E, and either an H rating for contaminants, yellow rating for acidity, or 5-percent dilution for the Kit D), a disparity of values between the two techniques was evident. More specifically, out of a total of 14 used oil samples considered "unsatisfactory" by either the Kit D or Kit E techniques, 13 were failed by Kit E whereas 7 were failed by the Kit D. In reviewing the validity of these recommended "failures" with the ASTM test data obtained on the individual oil samples, there exists a credibility factor to be considered. In several instances, the results obtained from the ASTM test methods would not warrant a recommendation for oil drain.

Some explanations for the lack of agreement cited above might be in order. For example, the blotter spot technique has limited applicability considering the increasing levels of additive treatment, changing of metal dispersant/detergents, upgrading of performance levels, etc. The acidity technique gives questionable values as only aqueous acids can be extracted. Moreover, with some of the new succinimide anhydride-derived ashless dispersants, these may be partially extracted and could produce a failing color change. The industry-accepted criteria for condemning/monitoring engine oil quality has been depletion of the alkalinity of the additive package (measured by Total Base No.). However, the kit's "Test for Acidity" will not assess this reduction in TBN. The test for fuel dilution via viscosity is particularly poor. The user is instructed to prepare "standard blends" using the respective fuel with the new oil. Two errors arise, here; namely, (1) not all new MIL-L-2104C/MIL-L-46152 oils will give equivalent viscosities unless they are the same formulation (identical QPL numbers) and (2) addition of the 5 percent of gasoline to new oil does not constitute the type of fuel dilutions which exists in the used oil, since its "composition" has been somewhat altered due to either vaporization or more volatile components or partial combustion of the fuel.

IV. CONCLUSIONS

Conclusions drawn from this work are as follows:

(1) Based on this work, the Test Kit A Acidity Test/Viscosity Comparator, and the Test Kit H Dielectric Constant Tester are the best combination of test kits for determining in-service lubricant condition.

(2) The Test Kit H dielectric constant tends to correlate with overall engine oil quality when identification of the lubricant is known.

(3) The Test Kit H is a good screening tool (i.e., "go-no go" lubricant condition) when the lubricant in the engine is known and when used in conjunction with other test kits.

(4) When the lubricants are mixed from the various qualified products, the Test Kit H can develop a problem, depending on the dielectric constant spread of the mixed lubricants.

(5) The Test Kit A acidity test appears not to change color or indicate acidity at a low enough level; but it was able to determine TAN of 6.9 or higher. The Test Kit A viscosity comparator test correlates quite well with ASTM D 445 viscosity at 40°C. The comparator reading of 6.5 or more appears to indicate poor oil and signals that an oil change should be made.

(6) The Test Kit A viscosity comparator test can differentiate between various viscosity grades such as Grade 50 and 30, or 10W/30.

(7) The Test Kit I miniature D 974 Colormeteric TAN correlates quite well with D 664 TAN; but there could be problems in adapting its use to field conditions (i.e., color definition, lightbox, etc.).

(8) The Test Kit F (filter absorption viscosity) compares favorably with the D 445 viscosity at 40°C when the exact same filter paper temperature and oil drop size are used.

(9) Blotter Spot tests provide fair results when determining the amount of solids present and the dispersancy left in the used oil. However, the blotter spot test requires considerable experience to interpret and the blotter spots are hard to maintain.

(10) No single test kit was found to independently determine the in-service condition of Army engine oils.

V. RECOMMENDATIONS

As a result of this program, the following recommendations are made:

- Independent use of any single field test kit to determine the condition of in-service used oil is not recommended on a routine basis, however, proper use of individual test kits might provide useful used-lubricant information.

- The Test Kit H should not be used by itself but as a screening tool in conjunction with several other test kits.

- Improvements in the Test Kit A viscosity comparator measuring readout system are required along with lower acidity readings that correlate to a TAN between 5.0 to 6.0.

- Simultaneous evaluation of the same oil samples using Test Kit A and H should be conducted under actual field conditions.

- A correlation of the Test Kit H kit with the Test Kit F should be attempted because Test Kit F did not correlate well with ASTM laboratory tests in the 1968-69 Navy vehicle fleet test.

- There is a need for a portable acidity tester, usable under Army field conditions, which would provide accurate TAN values in the range of 5.0 to 8.0.

- Also, pH should be investigated as an indicator of used-oil acidity and adapted to in-field portable usage if possible.

- More specific used-oil condemning limits should be established for Army-type operations in both tactical and administrative vehicles.

- Develop a kit which correlates with insolubles.

- An oil quality test kit independent of new oil properties is needed for situations in which a combination of mineral-based and synthetic-based lubricants are in use.

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APPENDIX A

LABORATORY ENGINE TEST DATA

TABLE A-1. ASTM USED OIL ANALYSES VERSUS TEST KIT G USING AL-6212-L LUBRICANT

	Test No. 1		Test No. 2		
Property	New	210 Hr	70 Hr	140 Hr	210 Hr
K. Viscosity, cSt					
at 100°F	121.60	119.8	134.0	139.0	140.20
at 210°F	12.61	12.91	13.33	13.64	13.94
VI	94	109	101	100	102
TAN	3.6	3.47	3.26	3.36	3.46
TBN	5.4	4.43	4.28	3.73	3.79
Metals, ppm					
Na	40	62	43	47	47
Cu	---	< 50	---	---	< 1
Pb	---	2	---	---	12
Fe	<1	110	69	90	91
Sn	---	< 1	---	---	< 100
Carbon Residue	1.19	1.77			1.59
Test Kit G Dielectric Constant	0	2.8	1.6	2.4	2.3

TABLE A-2. ASTM USED OIL ANALYSES VERSUS TEST KIT G USING AL-6409-L LUBRICANT, ENGINE TEST NO. 3

Property	ASTM Method	Test Hours								
		New	15	30	45	60	75*	90	105	120
K. Viscosity, cSt										
at 100°F	D 445	44.68	50.82	53.56	56.88	59.11	61.67	63.48	64.38	65.49
at 210°F	D 445	6.54	7.30	7.69	7.97	8.07	8.40	8.53	8.52	8.58
TAN	D 664	2.19	2.42	2.85	3.01	3.10	3.44	3.54	3.70	3.68
TBN	D 2896	11.12	11.43	12.02	12.27	12.55	12.55	12.55	12.69	13.24
Fe, ppm	XRF	1	40	90	130	150	160	190	220	210
Pentane Insol, wt% (w/coag)	D 893	0	--	--	--	0.05	--	--	--	0.55
Benzene Insol, wt% (w/coag)	D 893	0	--	--	--	0.04	--	--	--	0.47
Sulfated Ash, wt%	D 874	1.58	--	--	--	2.07	--	--	--	2.32
Carbon Residue, wt%	D 524	1.48	--	--	--	2.61	--	--	--	3.27
Flash Point, °C	D 92	430	--	--	--	445	--	--	--	445
Dielectric Constant (Kit G)		0	1.7	2.5	3.4	3.35	4.3	4.5	4.6	5.3

* The NI-1A Kit predicted the wear problem in this test at 75 to 90 hours.

TABLE A-3. ASTM USED OIL ANALYSES VERSUS VARIOUS MOBILE TEST KITS USING AL-6211-L LUBRICANT, ENGINE TEST NO. 4

Property	ASTM Method	Test Hours New	15	30	45	60	75	90	105*	109
K. Viscosity, cSt										
at 100°F	D 445	115.7	118.1	122.7	124.3	126.3	128.6	131.4	193.8	216.6
at 210°F	D 445	11.79	12.01	12.30	12.55	12.65	12.82	12.88	15.51	16.88
TAN	D 664	1.64	1.45	1.27	1.19	1.13	0.93	1.78	8.97	11.33
TBN	D 2896	4.47	3.93	3.45	3.18	2.83	2.96	2.63	2.16	0.97
Fe, ppm	XRF	---	25	25	25	35	30	35	50	140
Pentane Insol, wt% (w/coag)	D 893	---	---	---	---	0.02	---	---	---	0.75
Benzene Insol, wt% (w/coag)	D 893	---	---	---	---	0.01	---	---	---	0.66
Sulfated Ash, wt%	D 874	1.08	---	---	---	1.17	---	---	---	1.61
Carbon Residue, wt%	D 524	1.21	---	---	---	1.86	---	---	---	2.99
Flash Point, °F	D 92	500	---	---	---	515	---	---	---	470
IR Trace No.	---	1180	---	---	---	1181	---	---	---	1182
Other Wear Metals, ppm	XRF									
Cu		---	---	---	---	20	20	400	1000	270
Pb		---	---	---	---	20	30	40	830	1500
Mobile Test Kits										
Dielectric Constant										
Kit H		0	0.7	1.4	2.1	2.2	2.4	2.8	9.6	10.5
Acidity (Kit A)		Blue	Blue	Blue	Blue	Blue	Blue	Blue	Yellow	Yellow
Vis Comp. Kit A		0	---	0.8	---	1.2	---	1.4	6.4	7.2
Kit F Acidity		Blue	---	Blue	---	Blue	---	Blue	Blue/ Green	Green

--- = Not determined.
XRF = X-Ray Fluorescence.
* Three kits predicted the engine failure at 105 hours.

TABLE A-4. ASTM USED OIL ANALYSES VERSUS MOBILE TEST KITS USING AL-7062-L LUBRICANT, ENGINE TEST NO. 5

Property	ASTM Method	Test Hours New	70*	140*	210
K. Viscosity, cSt,	D 445				
at 40°C		104.6	111.8	111.0	110.8
at 100°C		11.8	12.5	12.5	12.5
VI	D 2270	101	---	---	---
TAN	D 664	3.6	3.4	3.2	3.3
TBN	D 2896	5.4	5.3	4.9	4.7
Insolubles, wt%	D 893				
Pentane A		0.05	0.02	0.02	0.03
Benzene A		0.04	0.02	0.01	0.01
Pentane B		0.03	0.30	0.26	0.19
Benzene B		0.02	0.17	0.19	0.15
API Gravity, °	D 287	27.5	---	---	---
Pour Point, °C	D 97	-21	---	---	---
Flash Point, °C	D 92	241	243	243	252
Carbon Residue, wt%	D 524	1.19	1.65	1.63	1.59
Sulfated Ash, wt%	D 874	0.93	1.14	1.14	1.12
Elemental	Method				
Ba, ppm	AA	Nil	---	---	---
Mg, ppm	AA	Nil	---	---	---
Ca, wt%	AA	0.24	0.28	0.28	0.30
Zn, wt%	AA	0.09	0.11	0.10	0.10
Fe, ppm	AA	---	53	59	60
Pb, ppm	AA	---	<1	<1	<1
Cu, ppm	AA	---	<1	<1	<1
Cr, ppm	AA	---	<1	<1	<1
Mobile Test Kits					
Dielectric Constant (Kit H)		0	1.7	1.6	1.4
Acidity (Kit A)		Blue	Blue	Blue	Blue
Vis Comp. Kit A		0	0.3	0.3	0.2

--- = Not Determined.
AA = Atomic Absorption.
* = Oil drained at 70 and 140 hours.
NI-1A kit checks were also made at 14, 28, 42, 56, 84, 112, 154, 168, 182 and 196 hours with the dielectric constant remaining essentially between the values of 1.7 and 1.4.

TABLE A-5. ASTM USED OIL ANALYSES VERSUS MOBILE TEST KITS USING AL-6942-L CANDIDATE SYNTHETIC 10W/30 LUBRICANT, ENGINE TEST NO. 6

Property	ASTM Method	Test Hours New	70	140	210
K. Viscosity, cSt,	D 445				
at 40°C		61.3	70.1	74.3	75.3
at 100°C		10.2	11.3	11.7	11.8
VI	D 2270	153	151	151	151
TAN	D 664	3.7	3.9	4.7	4.7
TBN	D 2896	10.2	9.2	9.2	9.2
Insolubles, wt%	D 893				
Pentane A		0.09	0.02	0.03	0.03
Benzene A		0.01	0.02	0.02	0.02
Pentane B		0.09	0.03	0.03	0.03
Benzene B		0.02	0.02	0.03	0.02
API Gravity, °	D 287	21.9	21.3	21.2	20.8
Pour Point, °C	D 97	-41	---	---	---
Flash Point, °C	D 92	227	229	232	232
Carbon Residue, wt%	D 524	1.53	1.92	2.08	2.14
Sulfated Ash, wt%	D 874	1.50	1.59	1.67	1.69
Elemental	Method				
Ba, ppm	AA	50	---	---	---
Mg, ppm	AA	11	---	---	---
Ca, wt%	AA/XRF	0.38/0.33	0.38	0.41	0.42
Zn, wt%	AA/SRF	0.18/0.16	0.18	0.19	0.19
Na, ppm	AA	10	---	---	---
Cu, ppm	XRF	---	6	7	6
Cr, ppm	AA	---	< 5	< 5	< 5
Pb, ppm	AA	---	8	12	11
Fe, ppm	AA/XRF	---	50/40	57/60	61/60
Mobile Test Kits					
Dielectric Constant (Kit H)		0	1.6	2.1	2.4
Acidity (Kit A)		Blue	Blue	Blue	Blue
Vis Comp. Kit A		0	1.8	2.0	2.4

--- = Not Determined.
AA = Atomic Absorption.
XRF = X-Ray Fluorescence.
Kit H checks were also made at 14, 28, 42, 56, 84, 112, 126, 154, 168, 182 and 196 hours with the dielectric constant remaining essentially between the values of 1.6 and 2.4.

TABLE A-6. ASTM USED OIL ANALYSES VERSUS VARIOUS MOBILE TEST KITS USING AL-6211-L LUBRICANT, ENGINE TEST NO. 7

Property	ASTM Method	Test Hours								
		New	15	30	45	60	75	90	105*	109
K. Viscosity, cSt										
at 40°C	D 445	102	104.38	106.26	108.91	108.75	109.29	115.89	190.84	225.55
at 100°C	D 445	10.6	11.57	11.92	11.89	12.03	11.99	12.22	15.82	17.75
TAN	D 664	1.64	1.42	1.26	1.21	1.26	1.32	1.53	11.96	14.49
TBN	D 2896	4.47	4.13	3.53	3.42	3.58	3.20	2.88	1.03	1.85
Fe, ppm	XRF	---	10	10	20	35	10	40	50	130
Pentane Insol, wt% (w/coag)	D 893	---	---	---	---	0.02	---	---	---	0.57
Benzene Insol, wt% (w/coag)	D 893	---	---	---	---	0.02	---	---	---	0.33
Sulfated Ash, wt%	D 874	1.08	---	---	---	1.13	---	---	---	1.53
Carbon Residue, wt%	D 524	1.21	---	---	---	1.27	---	---	---	1.98
Flash Point, °C	D 92	260	---	---	---	260	---	---	---	224
Other Wear Metals, ppm	XRF									
Cu		---	---	---	---	---	---	---	150	245
Pb		---	---	---	---	---	---	---	1100	1450
Mobile Test Kits										
Dielectric Constant (Kit H)		0	0.9	1.5	1.9	2.0	2.2	2.6	10.8	12.0
Acidity (Kit A)		Blue	Blue	Blue	Blue	Blue	Blue	Blue	Yellow	Yellow
Vis Comp. Kit A		0	---	0.6	---	1.0	---	1.8	6.2	7.4

--- = Not determined.
XRF = X-Ray Fluorescence.
* All three kits predicted the engine failure at 105 hours.

TABLE 4-7. ASTM USED OIL ANALYSIS VERSUS PART II MOBILE
TEST KITS USING AL-7022-L CANDIDATE LUBRICANT, ENGINE TEST NO. 2

Property	Test Hours: New	12	24	36	48	60	72	84	100
K. Viscosity, cSt									
at 40°C	30.1	31.50	32.07	32.11	32.75	32.77	32.82	32.77	33.07
at 100°C	5.85	6.14	5.19	6.22	6.26	6.36	6.29	6.40	6.47
TAN	2.28	2.9	3.5	3.6	3.6	3.8	3.8	3.7	4.1
TBN	5.95	5.6	5.4	5.4	5.3	5.4	5.3	5.7	5.3
Sulfated Ash, wt%	1.07	---	---	---	---	---	---	---	1.2
Flash Point, °F	232	---	---	---	---	---	---	---	227
Iron, ppm	0	30	40	30	65	40	55	190	270
Mobile Test Kits									
Dielectric Constant (Kit H)	0	0.6	0.0	0.2	0.4	0.3	0.3	0.3	0.6
Acidity (Kit A)	Blue	Blue	---	Blue	---	---	Blue	Blue	Blue
Vis Comp. Kit A	0	0.2	---	0.8	---	---	0.9	0.8	1.0
Kit F Acidity	Blue	Blue	---	Blue/Green	---	---	Blue/Green	Blue/Green	Blue/Green

--- = Not determined.

TABLE A-8. ASTM USED OIL ANALYSES VERSUS VARIOUS MOBILE TEST KITS USING AL-7219-L LUBRICANT, ENGINE TEST NO. 9

Property	ASTM Method	Test Hours New	70	140	210
K. Viscosity, cSt,	D 445				
at 40°C		104.6	109.6	114.4	115.8
at 100°C		11.8	12.4	12.8	13.0
VI	D 2270	101	104	105	106
TAN	D 664	2.1	3.1	3.2	3.2
TBN	D 2896	5.2	4.9	4.5	4.1
Insolubles, wt%	D 893				
Pentane A		0.02	---	---	0.02
Benzene A		0.02	---	---	0.02
Pentane B		0.03	---	---	0.12
Benzene B		0.02	---	---	0.09
API Gravity, °	D 287	27.5	---	---	27.5
Pour Point, °C	D 97	-21	---	---	---
Flash Point, °C	D 92	241	243	243	243
Carbon Residue, wt%	D 524	1.19	1.57	1.71	1.72
Sulfated Ash, wt%	D 874	1.00	1.11	1.17	1.18
Elemental	Method				
Ba, ppm	AA	Nil	---	---	---
Mg, ppm	AA	Nil	---	---	---
Ca, wt%	AA	0.27	0.28	0.31	0.30
Zn, wt%	AA	0.10	0.11	0.12	0.11
Cu, ppm	AA	---	9	9	10
Cr, ppm	AA	---	< 1	3	4
Pb, ppm	AA	---	95	119	103
Fe, ppm	XRF/AA	---	60/56	80/72	90/78
Mobile Test Kits					
Dielectric Constant (Kit H)		0	1.4	1.7	1.8
Acidity (Kit A)		Blue	Blue	Blue	Blue
Vis Comp. Kit A		0	0.6	1.4	1.6

--- = Not Determined
AA = Atomic Absorption
XRF = X-Ray Fluorescence
Kit H checks were also made at 14, 28, 42, 56, 84, 98, 112, 126, 154, 168, 182, and 196 hours with the dielectric constant remaining essentially between the values of 1.4 and 1.8.

TABLE A-9. ASTM USED OIL ANALYSES VERSUS VARIOUS MOBILE TEST KITS USING AL-6214-L LUBRICANT, ENGINE TEST NO. 10

Property	Test Hours: New	12	24	36	48	54*
K. Viscosity, cSt,						
at 40°C	33.8	35.8	36.4	37.4	43.9	49.7
at 100°C	5.7	5.9	6.0	6.1	6.5	7.1
VI						
TAN	1.58	1.65	1.61	1.83	4.12	6.41
TBN	5.19	4.64	4.02	3.46	1.42	0.79
Flash Point, °C	218	---	---	---	---	216
Sulfated Ash, wt%	1.14	---	---	---	---	1.40
Carbon Residue, wt%	1.20	---	---	---	---	2.05
Iron, ppm	---	45	80	120	175	185
Mobile Test Kits						
Dielectric Constant (Kit H)	0	1.4	2.1	2.6	6.4	9.7
Acidity (Kit A)	Blue	Blue	Blue	Blue	Green	Yellow
Vis Comp. Kit A	0	1.9	2.0	2.2	4.0	5.2

--- = Not Determined.
* Lost Power.

TABLE A-10. ASTM USED OIL ANALYSES VERSUS VARIOUS MOBILE TEST KITS USING AL-7135-L CANDIDATE SYNTHETIC LUBRICANT, ENGINE TEST NO. 11

Property	ASTM Method	Test Hours New	70	140	210
K. Viscosity, cSt,	D 445				
at 40°C		67.5	69.6	71.2	71.0
at 100°C		9.96	10.38	10.45	10.52
VI	D 2270	143	135	133	135
TAN	D 664	2.5	3.3	3.5	3.6
TBN	D 2896	7.9	6.5	4.7	4.6
Insolubles, wt%	D 893				
Pentane A		0.03	---	---	0.4
Benzene A		0.01	---	---	0.26
Pentane B		0.01	---	---	0.03
Benzene B		0.01	---	---	0.23
API Gravity, °	D 287	18.4	---	---	18.0
Pour Point, °C	D 97	-34	---	---	---
Flash Point, °C	D 92	227	263	265	260
Carbon Residue, wt%	D 524	1.12	1.57	1.75	1.82
Sulfated Ash, wt%	D 874	1.02	1.04	1.05	1.06
Elemental	Method				
Ba, ppm	AA	<50	---	---	---
Mg, wt%	AA	0.08	---	---	---
Ca, wt%	XRF	0.09	0.08	0.09	0.09
Zn, wt%	AA	0.13	0.11	0.115	0.115
Na, ppm	AA	<10	---	---	---
Cu, ppm	AA	---	<1	<1	<1
Cr, ppm	AA	---	<1	<1	<1
Pb, ppm	AA	---	7	12	16
Fe, ppm	AA	---	53	74	87
Mobile Test Kits					
Dielectric Constant (Kit H)		0	0.2	1.7	2.1
Acidity (Kit A)		Blue	Blue	Blue	Blue
Vis Comp. Kit A		0	0.9	1.4	1.7

--- = Not Determined.
AA = Atomic Absorption.
XRF = X-Ray Fluorescence.
Kit H checks were also made at 14, 28, 42, 56, 84, 98, 112, 126, 154, 168, 182, and 196 hours with the dielectric constant remaining essentially between the values of 0.2 and 2.1.

TABLE A-11. ASTM USED OIL ANALYSES VERSUS VARIOUS MOBILE TEST KITS USING AL-7283-L CANDIDATE LUBRICANT, ENGINE TEST NO. 12

Property	Test Hours New	12	24	36	48	60	72	84	100
K. Viscosity, cSt									
at 40°C	29.8	30.53	30.34	30.55	30.72	30.91	31.08	31.30	31.41
at 100°C	6.02	6.12	5.97	6.00	6.12	6.05	6.08	6.13	6.14
TAN	2.44	2.4	2.5	2.8	2.8	2.8	3.0	2.7	3.3
TBN	6.78	6.0	6.3	6.5	6.7	6.0	6.2	6.7	5.2
Sulfated Ash, wt%	1.41	---	---	---	---	---	---	---	1.2
Flash Point, °C	227	---	---	---	---	---	---	---	232
Iron, ppm	0	40	95	160	175	182	210	230	252
Mobile Test Kits									
Dielectric Constant (Kit H)	0	-1.4	-0.7	0.5	1.1	1.2	1.3	1.5	1.6
Acidity (Kit A)	Blue	Blue	---	Blue	---	---	Blue	---	Blue
Vis Comp. Kit A	0	0.6	---	1.2	---	---	1.8	---	2.1

--- = Not Determined.

TABLE A-12. ASTM USED OIL ANALYSES VERSUS VARIOUS MOBILE TEST KITS USING AL-7287-L LUBRICANT, ENGINE TEST NO. 13

Property	ASTM Method	Test Hours New	70	140	210
K. Viscosity, cSt,	D 445				
at 40°C		103.3	126.6	134.0	136.6
at 100°C		11.4	13.1	13.7	13.9
VI	D 2270	96	96	97	98
TAN	D 664	2.2	3.6	3.9	4.4
TBN	D 2896	13.7	12.8	13.2	12.3
Insolubles, wt%	D 893				
Pentane A		---	---	---	0.07
Benzene A		---	---	---	0.06
Pentane B		---	---	---	0.08
Benzene B		---	---	---	0.07
API Gravity, °	D 287	25.5	---	---	24.2
Pour Point, °C	D 97	-21	---	---	---
Flash Point, °C	D 92	227	241	241	241
Carbon Residue, wt%	D 524	1.82	2.74	2.69	2.91
Sulfated Ash, wt%	D 874	1.63	1.96	2.08	2.13
Elemental	Method				
Ba, ppm	AA	<50	---	---	---
Mg, ppm	AA	20	---	---	---
Ca, wt%	AA	0.40	0.50	0.52	0.54
Zn, wt%	AA	0.14	0.18	0.17	0.18
Na, ppm	AA	620	---	---	---
Cu, ppm	AA	---	5	6	6
Cr, ppm	AA	---	3	4	5
Pb, ppm	AA	---	6	6	8
Fe, ppm	XRF/AA	---	52/58	85/75	85/82
P, wt%	XRF	0.11	---	---	---
S, wt%	XRF	0.43	---	---	---
Mobile Test Kits					
Dielectric Constant (Kit H)		0	2.1	2.2	2.4
Acidity (Kit A)		---	Blue	Blue	Blue
Vis Comp. Kit A		0	2.4	2.7	2.8

--- = Not Determined.
AA = Atomic Absorption.
XRF = X-Ray Fluorescence.
Kit H checks were also made at 14, 28, 42, 56, 84, 98, 112, 126, 154, 168, 182, and 196 hours with the dielectric constant remaining essentially between the values of 2.1 and 2.4.

TABLE A-13. ASTM USED OIL ANALYSES VERSUS VARIOUS MOBILE TEST KITS USING AL-6711-L LUBRICANT, ENGINE TEST NO. 14

Property	ASTM Method	Test Hours: New	15	30	45	60	75	90	105	120
K. Viscosity, cSt										
at 40°C	D 445	64.24	62.84	66.42	71.66	73.72	77.23	78.56	79.05	80.17
at 100°C	D 445	11.27	10.65	11.02	11.46	11.82	12.13	12.29	12.43	12.50
TAN	D 664	2.01	2.62	3.15	3.68	3.99	4.27	4.58	4.72	5.06
TBN	D 2896	8.51	8.65	9.22	8.79	8.51	9.90	9.42	8.95	9.42
Pentane Insol, wt% (w/coag)	D 893	---	---	---	---	0.03	---	---	---	0.03
Benzene Insol, wt% (w/coag)	D 893	---	---	---	---	0.03	---	---	---	0.03
Sulfated Ash, wt%	D 874	---	---	---	---	1.54	---	---	---	1.72
Flash Point, °C	D 92	---	---	---	---	221	---	---	---	218
Wear Metals, ppm	XRF									
Fe		9	55	107	122	131	147	156	146	154
Mobile Test Kits										
Dielectric Constant (Kit H)		0	1.4	1.9	2.5	2.7	2.6	2.6	2.9	3.2
Acidity (Kit A)		Blue	Blue	---	---	Blue	---	---	---	Blue
Vis Comp. Kit A		0	2.1	---	---	3.2	---	---	---	4.6

--- = Not Determined.
XRF = X-Ray Fluorescence.

TABLE A-14. ASTM USED OIL ANALYSES VERSUS VARIOUS MOBILE TEST KITS USING AL-7326-L LUBRICANT, ENGINE TEST NO. 15

Property	ASTM Method	Test Hours New	70	140	210
K. Viscosity, cSt,	D 445				
at 40°C		106.0	117.6	120.9	122.2
at 100°C		11.8	12.5	13.0	13.0
VI	D 2270	99	98	100	100
TAN	D 664	2.0	3.3	3.6	5.4
TBN	D 2896	10.7	10.0	10.2	10.2
Insolubles, wt%	D 893				
Pentane A		---	---	---	0.12
Benzene A		---	---	---	0.05
Pentane B		---	---	---	0.55
Benzene B		---	---	---	0.41
API Gravity, °	D 287	27.8	---	---	27.2
Pour Point, °C	D 97	15	---	---	---
Flash Point, °C	D 92	246	---	---	254
Carbon Residue, wt%	D 524	1.28	1.67	1.82	1.92
Sulfated Ash, wt%	D 874	1.41	1.65	1.68	1.71
Elemental	Method				
Ba, ppm	AA	<25	---	---	---
Mg, ppm	AA	9	---	---	---
Ca, wt%	AA	0.35	0.41	0.40	0.44
Zn, wt%	AA	0.14	0.13	0.14	0.15
Na, ppm	AA	12	---	---	---
Cu, ppm	AA	---	3	4	4
Cr, ppm	AA	---	2	2	2
Pb, ppm	AA	---	6	4	5
Fe, ppm	AA	---	27	35	39
Mobile Test Kits					
Dielectric Constant (Kit H)		0	1.6	1.8	2.1
Acidity (Kit A)		Blue	Blue	Blue	Blue
Vis Comp. Kit A		0	1.9	3.4	3.8

--- = Not Determined.
AA = Atomic Absorption.
Kit H checks were also made at 14, 28, 42, 56, 84, 98, 112, 126, 154, 168, 182, and 196 hours with the dielectric constant remaining essentially between the values of 1.6 and 2.1.

TABLE A-15. ASTM USED OIL ANALYSES VERSUS VARIOUS MOBILE TEST KITS USING AL-6950-L LUBRICANT, ENGINE TEST NO. 16

Property	ASTM Method	Test Hours New	70	140	210
K. Viscosity, cSt,	D 445				
at 40°C		59.67	56.00	58.85	60.09
at 100°C		10.96	9.68	10.03	10.01
VI	D 2270	178	158	158	153
TAN	D 664	2.0	2.3	2.5	2.8
TBN	D 2896	4.8	3.1	3.4	4.2
Insolubles, wt%	D 893				
Pentane A		---	---	---	0.08
Benzene A		---	---	---	0.12
Pentane B		---	---	---	0.05
Benzene B		---	---	---	0.10
API Gravity, °	D 287	29.1	---	---	27.1
Pour Point, °C	D 97	-30	---	---	---
Flash Point, °C	D 92	226	227	227	232
Carbon Residue, wt%	D 524	0.56	1.36	1.64	1.74
Sulfated Ash, wt%	D 874	0.73	0.85	0.95	1.00
Elemental	Method				
Ba, ppm	AA	400	---	---	---
Mg, ppm	AA	5	---	---	---
Ca, wt%	AA	0.20	0.23	0.26	0.26
Zn, wt%	AA	0.09	0.11	0.11	0.11
Cu, ppm	AA	---	5	6	9
Cr, ppm	AA	---	5	9	11
Pb, ppm	AA	---	9	9	11
Fe, ppm	AA/XRF	---	62/80	103/136	114/149
S, wt%	XRF	0.92	---	---	---
Mobile Test Kits					
Dielectric Constant (Kit H)		0	2.1	2.7	2.7
Acidity (Kit A)		Blue	Blue	Blue	Blue
Vis Comp. Kit A		0	1.4	3.0	3.0

--- = Not Determined
AA = Atomic Absorption
XRF = X-Ray Fluorescence
Kit H checks were also made at 14, 28, 42, 56, 84, 98, 112, 126, 154, 168, 182, and 196 hours with the dielectric constant remaining essentially between the values of 2.1 and 2.7.

TABLE A-16. ASTM USED OIL ANALYSES VERSUS VARIOUS MOBILE TEST KITS USING AL-6739-L LUBRICANT, ENGINE TEST NO. 17

Property	ASTM Method	Test Hours New	70	140	210
K. Viscosity, cSt,	D 445				
at 40°C		26.76	30.28	31.37	31.72
at 100°C		5.97	6.66	6.83	6.94
VI	D 2270	179	186	186	189
TAN	D 664	0.3	0.4	0.4	0.5
TBN	D 2896	6.3	4.3	4.8	4.3
Insolubles, wt%	D 893				
Pentane A		---	---	---	0.49
Benzene A		---	---	---	0.45
Pentane B		---	---	---	0.73
Benzene B		---	---	---	0.62
API Gravity, °	D 287	21.1	---	---	20.0
Flash Point, °C	D 92	249	249	249	246
Carbon Residue, wt%	D 524	1.48	2.03	2.31	2.50
Sulfated Ash, wt%	D 874	1.55	1.78	1.80	1.94
Elemental	Method				
Ba, ppm	AA	950	---	---	---
Mg, ppm	AA	1	---	---	---
Ca, wt%	AA	9	---	---	---
Zn, wt%	AA	4	---	---	---
P, wt%	Mod. oronite	0.01	---	---	---
S, wt%	XRF	0.02	---	---	---
Fe, ppm	AA/XRR	---	40/30	68/57	83/64
Cu, ppm	AA	---	3	4	6
Cr, ppm	AA	---	2	3	5
Pb, ppm	AA	---	6	1	4
Mobile Test Kits					
Dielectric Constant (Kit H)		0	1.5	2.6	2.7
Acidity (Kit A)		Blue	Blue	Blue	Blue
Vis Comp. Kit A		0	2.6	3.5	3.5

--- = Not Determined
AA = Atomic Absorption
XRF = X-Ray Fluorescence
Kit H checks were also made at 14, 28, 42, 56, 84, 98, 112, 126, 154, 168, 182, and 196 hours with the dielectric constant remaining essentially between the values of 1.5 and 2.7.

APPENDIX B

FIELD TEST DATA

TABLE B-1. VEHICLE 890 - AL-5936-L MIL-L-46152 10W/30

Sample Date	Miles/ Month	K. Viscosity		D 664 TAN	Kit G (Range 1)**
		at 100°F	at 210°F		
10-2-75	1151	67.1	10.05	2.84	0
11-3-75	1871	73.3	10.51		2.3
12-5-75	1529	74.5	10.75		2.9
1-20-76	560	74.3			3.2
2-11-76	1116				3.5
3-2-76	725				3.7
4-5-76	1377	83.2			3.8
5-11-76	947	81.3			3.8
6-3-76	192	85.2			4.0
7-6-76	24	73.6			3.8
8-3-76	2				4.1
9-2-76*	24	290.1	- Water in Oil -		Off-Scale
10-5-76	1239	66.5		2.51	3.0
11-1-76	0	66.5		2.45	3.0
12-8-76	Transmission Repair				
1-18-77	406	64.1			3.7
2-8-77	991	80.6			2.3
3-10-77	40	70.3			1.8
4-8-77	134				2.0
5-6-77	361				2.8

* Filter Change.
** 4.0 is safe rejection zone.

TABLE B-2. VEHICLE 891 - AL-6095-L MIL-L-46152 10W/30

Sample Date	Miles/ Month	K. Viscosity at 100°F	K. Viscosity at 210°F	D 664 TAN	Kit G (Range 1)**
10-1-75	2206	98.9	13.7	3.0	0
11-4-75	1571	124.8	15.8	3.58	3.8
12-4-75*	1881	137.9	17.0		4.0
1-12-76	2308	108.0	14.7		3.0
2-6-76	1022	112.8			3.4
3-4-76	0				3.4
4-6-76	0	99.1			3.6
5-12-76	260				3.0
6-1-76	1437				3.2
7-1-76	1417	155.0			3.7
8-2-76	616	155.1			3.9
9-1-76	1465	168.9			4.0
10-8-76	1558	222.0		5.39	4.5
11-1-76*	2348	244.5	24.9	6.99	4.7
12-8-76	573	102.6		3.70	2.6
1-18-77	883				3.4
2-11-77	305	131.2			3.6
3-8-77	1673				3.8
4-6-77	2088	236.1			4.6

* Oil Change.
** 4.00 is safe rejection zone.

TABLE B-3. VEHICLE 289 AL-5941-L MIL-L-46152 SYNTHETIC 10W/40

Sample Date	Miles/ Month	K. Viscosity at 100°F	K. Viscosity at 210°F	D 664 TAN	Kit G (Range 2)**
10-3-75	1839	78.8	12.8	2.84	0
11-3-75	2648				1.6
12-5-75	965				1.7
1-20-76	1902	89.4			2.0
2-9-76	1823	104.1			2.2
3-9-76	846				2.9
4-2-76	1585	118.2			3.75
5-4-76	1639				---
6-2-76	2642	139.2			6.0
7-7-76	1305	163.5			7.5
8-3-76	662	161.7			8.0
9-8-76	1490	166.2			8.8
10-7-76	1356	175.3		7.57	8.1
11-4-76*	664	173.7		7.99	8.6
12-7-76	523	83.1		2.84	1.8
1-13-77	1288				3.6
2-11-77	726	113.3			4.6
3-11-77	557				4.8
4-7-77	698	114.2			4.7

* Oil Change.

** 6.00 is safe rejection zone.

TABLE B-4. VEHICLE 291 AL-6088-L MIL-L-46152 SYNTHETIC 10W/30

Sample Date	Miles/ Month	K. Viscosity at 100°F	K. Viscosity at 210°F	D 664 TAN	Kit G (Range 2)**
10-6-75	2034	63.2	10.6	2.38	2.4
11-5-75	1863	69.3	11.3		2.7
12-4-75	630				2.6
1-15-76	2253	61.96			2.7
2-11-76	1488	75.6			4.0
3-10-76	1338				4.4
4-6-76	2671	87.1			4.7
5-5-76	1609				
6-3-76	1024				
7-6-76	1704	105.5			5.7
8-3-76	1417				
9-3-76	977	92.3			4.8
10-6-76	1873	110.0		6.54	5.5
11-3-76	839	113.3		7.08	6.5
12- -76		Off Post			
1-12-77	3409	125.7			7.2
2-8-77	936	158.4		9.13	7.5
3-11-77*	1865	156.4			8.0
4-8-77	842	55.8			2.1

* Oil Change.

** 6.00 is safe rejection zone.

TABLE B-5. M60A1 ENGINE OIL PILOT FIELD TEST
(Tank No. B-11*, MIL-L-2104C OE/HDO-30)

Properties	New	15 Sept To 15 Nov 1977	30 Nov 1977 AL-7207-L	Dec 1977	Jan 1978 AL-7259-L
K. Viscosity, cSt					
at 40°C	120.0		141.0		131.7
at 100°C	11.9		14.8		14.1
VI	96		104		105
TAN	1.98		2.16		2.47
TBN	12.0		8.25		7.61
Flash Point, °C	244		230		207
Metals, ppm					
XRF (Filter)					
Fe		Not sampled	43	Not sampled	103
Pb			< 50		
Cu			20		23
Sn			< 50		< 50
Cr			< 10		< 10
Mo			< 50		< 50
Si			22		81
Al			36		93
AA					
Fe			65		145
Pb					10
Mobile Test Kits					
Dielectric Cons. Kit H	0		2.1		2.0
Acidity Kit A	Blue		Blue		Blue
Vis Comp. Kit A	0		2.6		2.5

* Tank No. Originally HQ-66

TABLE B-6. M60A1 ENGINE OIL PILOT FIELD TEST
(Tank No. HQ-67, MIL-L-46167 5W/20)

Properties	New	15 Sept To 15 Nov 1977 AL-7200-L	30 Nov 1977 AL-7214-L	Dec 1977 AL-7228-L	Jan 1978
K. Viscosity, cSt					
at 40°C	29.3	34.7	34.1	33.4	
at 100°C	6.1	8.3	7.6	7.3	
VI	185	226	199	192	
TAN	0.22	0.71	0.63	0.74	
TBN	7.8	7.49	7.46	6.90	
Flash Point, °C	244	240	241	232	
Metals, ppm					Not sampled
XRF (Filter)					
Fe		81	72	89	
Pb		<50	<50	< 50	
Cu		127	104	124	
Sn		<50	<50	< 50	
Cr		<10	<10	< 10	
Mo		<50	<50	< 50	
Si		29	12	27	
Al		40	40	64	
AA					
Fe		100	82	97	
Pb					
Mobile Test Kits					
Dielectric Cons. Kit H	0	2.5	2.3	1.8	
Acidity Kit A	Blue	Blue	Blue	Blue	
Vis Comp. Kit A	0	2.6	3.2	2.8	

TABLE B-7. M60A1 ENGINE OIL PILOT FIELD TEST
(Tank No. HQ-68, MIL-L-46167 5W/20)

Properties	New	15 Sept To 15 Nov 1977 AL-7201-L	30 Nov 1977 AL-7208-L	Dec 1977 AL-7229-L	Jan 1978 AL-7260-L*
K. Viscosity, cSt					
at 40°C	29.3	31.1	30.1	30.0	29.2
at 100°C	6.1	7.3	6.8	6.6	6.4
VI	185	213	193	183	182
TAN	0.22	0.55	0.61	0.74	0.88
TBN	7.8	8.09	7.93	7.72	7.89
Flash Point, °C	244	246	241	232	224
Metals, ppm					
XRF (Filter)					
Fe		155	122	123	189
Pb		< 50	<50	< 50	< 50
Cu		54	43	50	32
Sn		< 50	<50	< 50	< 50
Cr		< 10	<10	< 10	< 10
Mo		< 50	<50	< 50	110
Si		105	85	110	139
Al		102	78	108	129
AA					
Fe		138	130	154	227
Pb					44
Mobile Test Kits					
Dielectric Cons. Kit H	0	3.8	3.1	3.9	-4.6
Acidity Kit A	Blue	Blue	Blue	Blue	Blue
Vis Comp. Kit A	0	2.4	2.6	1.8	1.6

* A lubricant prepared by Conoco was added in January 1978.

TABLE B-8. M60A1 ENGINE OIL PILOT FIELD TEST
(Tank No. A-31, MIL-L-46167, 5W/20*)

Properties	New	15 Sept To 15 Nov 1977 AL-7202-L	30 Nov 1977 AL-7209-L	Dec 1977 AL-7230-L	Jan 1978 AL-7261-L
K. Viscosity, cS					
at 40°C	29.3	38.7	38.6	37.1	37.8
at 100°C	6.1	7.5	7.4	7.7	7.4
VI	180	164	163	182	167
TAN	0.22	0.95	0.98	0.79	1.07
TBN	7.8	8.85	8.55	8.32	8.68
Flash Point, °C	244	238	246	235	227
Metals, ppm					
XRF (Filter)					
Fe		89	140	122	154
Pb		< 50	< 50	< 50	< 50
Cu		41	52	54	50
Sn		< 50	< 50	< 50	< 50
Cr		< 10	< 10	< 10	< 10
Mo		< 50	< 50	110	< 50
Si		94	135	198	218
Al		104	143	200	220
AA					
Fe		138	157	150	206
Pb					50
Mobile Test Kits					
Dielectric Cons. Kit H	0	-10.2	-9.6	-9.4	-9.1
Acidity Kit A	Blue	Blue	Blue	Blue	Blue
Vis Comp. Kit A	0	4.2	4.2	4.8	4.2

* Was a mixture of two APG PD-1 products, thereby giving the negative reading on the dielectric constant.

TABLE B-9. M60A1 ENGINE OIL PILOT FIELD TEST
(Tank No. A-32, MIL-L-46167, 5W/20*)

Properties	New	15 Sept To 15 Nov 1977 AL-7202-L	30 Nov 1977 AL-7209-L	Dec 1977 AL-7230-L	Jan 1978 AL-7261-L
K. Viscosity, cS			Not Sampled Because Engine Was Replaced and Had No Synthetic Oil	Not Sampled Because Engine Was Replaced and Had No Synthetic Oil	Not Sampled Because Engine Was Replaced and Had No Synthetic Oil
at 40°C	29.3	49.2			
at 100°C	6.1	8.7			
VI	180	157			
TAN	0.22	1.11			
TBN	7.8	9.18			
Flash Point, °C	244	240			
Metals, ppm					
XRF (Filter)					
Fe		179			
Pb		50			
Cu		24			
Sn		50			
Cr		10			
Mo		50			
Si		385			
Al		344			
AA					
Fe		219			
Pb					
Mobile Test Kits					
Dielectric Cons. Kit H	0	+(-12.0)			
Acidity Kit A	Blue	Blue			
Vis Comp. Kit A	0	6.2			

* Was a mixture of two APG PD-1 products, thereby giving the negative reading on the dielectric constant.

TABLE B-10. M60A1 ENGINE OIL PILOT FIELD TEST
(Tank No. A-33, MIL-L-46167, 5W/20*)

Properties	New	15 Sept To 15 Nov 1977 AL-7202-L	30 Nov 1977 AL-7209-L	Dec 1977 AL-7230-L	Jan 1978 AL-7261-L
K. Viscosity, cSt					
at 40°C	29.3	54.3	52.6	51.5	44.2
at 100°C	6.1	10.0	9.4	9.6	8.3
VI	180	168	164	174	167
TAN	0.22	1.50	1.61	1.73	1.62
TBN	7.8	8.36	8.36	7.61	8.12
Flash Point, °C	244	235	235	210	204
Metals, ppm					
XRF (Filter)					
Fe		70	63	76	57
Pb		<50	<50	<50	<50
Cu		33	20	46	46
Sn		<50	<50	<50	<50
Cr		<10	<10	<10	<10
Mo		<50	<50	<50	<50
Si		12	10	21	45
Al		46	33	68	60
AA					
Fe		110	130	106	111
Pb					59
Mobile Test Kits					
Dielectric Cons. Kit H	0	+(-12)	+(-12)	+(-12)	+(-12)
Acidity Kit A	Blue	Blue	Blue	Blue	Blue
Vis Comp. Kit A	0	6.4	6.4	6.4	5.4

* Was a mixture of two APG PD-1 products, thereby giving the negative reading on the dielectric constant.

TABLE B-11. M60A1 ENGINE OIL PILOT FIELD TEST
(Tank No. A-34, MIL-L-46167, 5W/20*)

Properties	New	15 Sept To 15 Nov 1977 AL-7202-L	30 Nov 1977 AL-7209-L	Dec 1977 AL-7230-L	Jan 1978 AL-7261-L
K. Viscosity, cSt					
at 40°C	29.3	65.3	65.3	56.5	37.5
at 100°C	6.1	10.9	10.6	10.0	7.3
VI	180	159	153	165	161
TAN	0.22	1.23	1.21	1.21	0.85
TBN	7.8	9.45	9.96	9.30	9.02
Flash Point, °C	244	252	255	238	232
Metals, ppm					
XRF (Filter)					
Fe		389	261	222	410
Pb		<50	<50	<50	
Cu		38	26	19	39
Sn		<50	<50	<50	<50
Cr		<10	<10	<10	<10
Mo		<50	<50	<50	<50
Si		792	624	442	585
Al		590	518	316	480
AA					
Fe		296	279	287	375
Pb					59
Mobile Test Kits					
Dielectric Cons. Kit H	0	+(-12)	+(-12)	+(-12)	+(-12)
Acidity Kit A	Blue	Blue	Blue	Blue	Blue
Vis Comp. Kit A	0	8.0	8.6	7.0	4.2

* Was a mixture of two APG PD-1 products, thereby giving the negative reading on the dielectric constant.

TABLE B-12. M60A1 ENGINE OIL PILOT FIELD TEST
(Tank No. A-35, MIL-L-46167, 5W/20*)

Properties	New	15 Sept To 15 Nov 1977 AL-7202-L	30 Nov 1977 AL-7209-L	Dec 1977 AL-7230-L	Jan 1978 AL-7261-L
K. Viscosity, cSt					
at 40°C	29.3	39.0	40.5	37.6	36.3
at 100°C	6.1	7.5	7.7	7.5	7.3
VI	180	161	161	171	170
TAN	0.22	0.69	0.90	1.00	1.04
TBN	7.8	8.36	8.42	7.99	8.17
Flash Point, °C	244	243	252	227	229
Metals, ppm					
XRF (Filter)					
Fe		187	213	164	218
Pb		< 50	< 50	< 50	
Cu		56	67	58	62
Sn		< 50	< 50	< 50	< 50
Cr		< 10	< 10	< 10	< 10
Mo		< 50	< 50	< 50	< 50
Si		75	80	86	117
Al		113	138	148	204
AA					
Fe		234	190	253	257
Pb					43
Mobile Test Kits					
Dielectric Cons. Kit B	0	-6.0	-8.0	-6.5	-7.0
Acidity Kit A	Blue	Blue	Blue	Blue	Blue
Vis Comp. Kit A	0	4.6	4.6	3.6	3.8

* Was a mixture of two APG PD-1 products, thereby giving the negative reading on the dielectric constant.

TABLE B-13. FT. SAM HOUSTON FLEET TEST USING
MIL-L-46152 10W/30 AND GRADE 30 OR 20W/40
(1973 Chevrolet Sedan - A29)

Properties	26 Apr 78 AL-7411-L	31 May 78 AL-7457-L	6 July 78 AL-7605-L	9 Aug 78 AL-7666-L	14 Sept 78* AL-7731-L
K. Viscosity, cSt					
at 40°C	128.7	148.4	166.9	129.7	64.2
at 100°C	12.2	13.3	14.2	13.0	9.6
VI	82	80	79	93	130
TAN	3.46	3.57	4.33	4.07	5.47
TBN	8.95	8.79	4.98	7.14	7.24
Flash Point, °C	232	227	232	204	204
Pentane Insol, wt% (w/coag)	0.10	0.63	1.60	1.72	0.08
Benzene Insol, wt% (w/coag)	0.06	0.23	0.70	0.62	0.05
Metals, ppm					
AA					
Fe	27	28	42	21	17
Pb	54	78	112	170	47
Cu	<1	2	2	2	1
Sn	<1	<1	5	<5	<5
Cr	<1	2	2	2	1
Si	4	<1	10	<5	<5
Al	3	5	7	<5	<5
Mileage	440	1376	1171	1287	1063
Mobile Test Kits					
Dielectric Cons. Kit B	4.2	5.3	5.8	5.6	2.5
Acidity Kit A	Blue	Blue	Blue	Blue	Blue
Vis Comp. Kit A	8.6(3.0)**	9.6(4.8)	9.8(5.7)	8.6(3.4)	4.2

* Oil was drained on 14 Aug 1978
** The numbers in parentheses used OE/HDO-30 as baseline.

TABLE B-14. FT. SAM HOUSTON FLEET TEST USING MIL-L-46152 10W/30 AND GRADE 30 OR 20W/40 (1972 Ford Sedan - A40)

Properties	26 Apr 78 AL-7409-L	31 May 78* AL-7458-L	6 July 78 AL-7606-L	9 Aug 78 AL-7667-L	14 Sept 78 AL-7732-L
K. Viscosity, cSt					
at 40°C	113.3	65.5	71.2	67.7	69.4
at 100°C	13.5	9.8	10.3	9.9	10.0
VI	117	131	129	130	127
TAN	5.54	2.67	2.38	3.29	6.47
TBN	6.09	4.84	2.82	4.79	3.48
Flash Point, °C	227	227	238	218	193
Pentane Insol, wt% (w/coag)	4.19	0.07	0.44	0.55	1.14
Benzene Insol, wt% (w/coag)	1.84	0.05	0.21	0.19	0.18
Metals, ppm					
AA					
Fe	86	17	23	23	31
Pb	6127	1049	1759	813	830
Cu	5	2	2	2	2
Sn	12	< 1	<1	< 5	<5
Cr	5	2	3	3	3
Si	16	< 1	<7	< 5	<5
Al	9	1	4	< 5	<5
Mileage	1090	919	1014	605	610
Mobile Test Kits					
Dielectric Cons. Kit H	4.1	1.7	1.8	1.9	2.4
Acidity Kit A	Blue	Blue	Blue	Blue	Blue
Vis Comp. Kit A	7.8(2.0)**	5.5	5.2	3.8	4.4

* Oil was drained on 4 May 1978.

** The numbers in parentheses used OE/HDO-30 as baseline.

TABLE B-15. FT. SAM HOUSTON FLEET TEST USING
MIL-L-46152 10W/30
(1972 Ford Sedan - A79)

Properties	26 Apr 78 AL-7407-L	31 May 78 AL-7459-L	6 July 78 AL-7607-L	9 Aug 78* AL-7668-L	14 Sept 78 AL-7733-L
K.Viscosity, cSt					
at 40°C	62.1	66.9	76.1	64.0	59.7
at 100°C	9.5	9.9	10.7	9.8	9.4
VI	133	131	127	135	138
TAN	3.07	4.41	4.02	2.75	4.36
TBN	7.73	5.96	5.84	7.97	7.26
Flash Point, °C	221	227	235	202	204
Pentane Insol, wt% (w/coag)	0.06	0.99	1.58	0.04	0.04
Benzene Insol, wt% (w/coag)	0.04	0.33	0.81	0.03	0.04
Metals, ppm					
AA					
Fe	24	26	34	8	10
Pb	340	1380	1189	270	79
Cu	< 1	2	1	1	1
Sn	< 1	< 1	< 1	< 5	< 5
Cr	< 1	2	3	< 1	< 1
Si	3	< 1	10	< 5	19
Al	< 5	2	4	< 5	< 5
Mileage	489	1220	1081	558	474
Mobile Test Kits					
Dielectric Cons. Kit H	1.9	3.1	3.4	2.0	2.1
Acidity Kit A	Blue	Blue	Blue	Blue	Blue
Vis Comp. Kit A	5.2	5.6	5.8	3.8	3.5

* Oil was drained on 8 Aug 1978

TABLE B-16. FT. SAM HOUSTON FLEET TEST USING MIL-L-46152 10W/30 AND GRADE 30 OR 20W/40 (1973 Chevrolet Sedan - A102)

Properties	26 Apr 78 AL-7408-L	31 May 78 AL-7460-L	6 July 78 AL-7608-L	9 Aug 78 AL-7669-L	14 Sept 78* AL-7734-L
K. Viscosity, cSt					
at 40°C	100.1	106.9	104.5	138.5	67.8
at 100°C	10.6	11.0	11.3	13.4	9.1
VI	86	86	93	90	110
TAN	2.56	3.01	2.90	4.56	4.47
TBN	8.95	7.01	7.82	7.14	7.51
Flash Point, °C	229	243	227	199	213
Pentane Insol, wt% (w/coag)	0.06	0.03	0.16	0.84	0.05
Benzene Insol, wt% (w/coag)	0.05	0.01	0.07	0.67	0.05
Metals, ppm					
AA					
Fe	19	16	21	25	16
Pb	848	929	1051	7375	1294
Cu	< 1	1	1	2	1
Sn	< 1	< 1	< 1	< 5	< 5
Cr	< 1	1	2	4	< 1
Si	14	< 1	10	< 5	85
Al	< 5	3	4	9	< 5
Mileage	357	380	209	2268	398
Mobile Test Kits					
Dielectric Cons. Kit H	3.9	4.5	4.7	5.2	2.3
Acidity Kit A	Blue	Blue	Blue	Blue	Blue
Vis Comp. Kit A	7.1(0.8)**	7.4(1.7)	7.2(1.2)	8.8(3.7)	5.1

* Oil was drained on 8 Sept 1978.
** The numbers in parentheses used OE/HDO-30 as baseline.

TABLE B-17. FT. SAM HOUSTON FLEET TEST USING
MIL-L-46152 10W/30
(1977 AMC Sedan - A716)

Properties	26 Apr 78 AL-7410-L	31 May 78 AL-7461-L	6 July 78 AL-7609-L	9 Aug 78 AL-7670-L	14 Sept 78 AL-7735-L
K. Viscosity, cSt					
at 40°C	59.8	62.9	62.9	58.0	56.2
at 100°C	9.0	9.2	9.3	8.9	8.6
VI	129	124	127	130	128
TAN	3.24	3.21	3.36	2.79	6.12
TBN	8.00	5.68	6.28	8.24	6.42
Flash Point, °C	216	235	227	163	191
Pentane Insol, wt% (w/coag)	0.09	0.16	0.11	0.08	0.03
Benzene Insol, wt% (w/coag)	0.07	0.14	0.05	0.03	0.02
Metals, ppm					
AA					
Fe	43	32	39	18	45
Cu	6	5	4	5	5
Sn	<1	<1	5	<5	<5
Cr	<1	2	21	1	2
Si	16	<1	12	<5	12
Al	11	6	7	8	8
Mileage	1217	392	576	317	211
Mobile Test Kits					
Dielectric Cons. Kit H	2.0	3.2	3.3	3.4	3.6
Acidity Kit A	Blue	Blue	Blue	Blue	Blue
Vis Comp. Kit A	3.8	5.0	4.6	3.6	3.2

TABLE B-18. FT SAM HOUSTON FLEET TEST USING
MIL-L-46152 10W/30
(1975 Ford Station Wagon - E502)

Properties	28 Mar 78 AL-7362-L	26 Apr 78 AL-7405-L	31 May 78 AL-7462-L	6 July 78 AL-7610-L	9 Aug 78* AL-7671-L	14 Sept 78 AL-7736-L
K. Viscosity, cSt						
at 40°C	66.3	66.8	73.5	77.9	63.3	62.5
at 100°C	9.9	9.8	10.9	10.6	9.7	9.5
VI	132	129	137	121	135	133
TAN	2.71	3.46	4.00	3.41	3.03	5.65
TBN	8.00	8.00	7.39	6.90	7.38	7.23
Flash Point, °C	204	199	227	235	191	218
Pentane Insol, wt% (w/coag)	0.08	0.15	0.19	0.46	0.08	0.04
Benzene Insol, wt% (w/coag)	0.05	0.10	0.05	0.24	0.04	0.02
Metals, ppm						
AA						
Fe	48	61	74	72	14	22
Pb	36	53	44	43	15	24
Cu	4	4	5	4	2	2
Sn	<3	<1	<1	<1	< 5	<5
Cr	1	4	7	7	< 1	1
Si	<10	7	<1	11	< 5	<5
Al	3	<5	4	4	< 5	<5
Mileage	1680	532	1133	695	658	233
Mobile Test Kits						
Dielectric Cons. Kit H	1.9	2.0	3.3	3.8	2.1	2.3
Acidity Kit A	Blue	Blue	Blue	Blue	Blue	Blue
Vis Comp. Kit A	4.5	4.6	6.6	6.2	4.0	3.9

* Oil was drained on 4 Aug 1978

TABLE B-19. FT. SAM HOUSTON FLEET TEST USING
MIL-L-46152 10W/30 AND GRADE 30 OR 20W/40
(1975 Ford Station Wagon - E503)

Properties	28 Mar 78 AL-7368-L	26 Apr 78 AL-7406-L	31 May 78 AL-7463-L	6 July 78*	9 Aug 78 AL-7672-L	14 Sept 78 AL-7737-L
K. Viscosity, cSt						
at 40°C	61.6	57.7	69.4		106.7	115.1
at 100°C	9.3	9.0	10.0		11.9	12.5
VI	130	133	126		100	99
TAN	2.84	2.95	4.08		2.21	4.77
TBN	7.04	6.34	8.62		10.42	9.33
Flash Point, °C	216	207	177		177	229
Pentane Insol, wt% (w/coag)	0.69	0.11	0.27		0.09	0.05
Benzene Insol, wt% (w/coag)	0.05	0.08	0.08		0.08	0.01
Metals, ppm				On TDY, not sampled.		
AA						
Fe	28	41	40		27	57
Pb	39	51	51		21	43
Cu	2	<1	3		3	3
Sn	<3	<1	<1		<5	<5
Cr	<1	<1	2		2	2
Si	<1	11	<1		<5	22
Al	<3	5	4		11	9
Mileage	1093	706	1269		4386	899
Mobile Test Kits						
Dielectric Cons. Kit H	1.7	1.8	2.9		2.3	2.6
Acidity Kit A	Blue	Blue	Blue		Blue	Blue
Vis Comp. Kit A	4.2	3.8	6.4		7.5(0.4)**	7.9(1.7)

* Apparently drained while on TDY.
** The numbers in parentheses used OE/HDO-30 as baseline.

TABLE B-20. FT. SAM HOUSTON FLEET TEST USING
MIL-L-46152 10W/30
(1972 Chevrolet Pickup - G13)

Properties	28 Mar 78 AL-7364-L	26 Apr 78 AL-7401-L	31 May 78 AL-7464-L	6 July 78 AL-7612-L	9 Aug 78 AL-7637-L	14 Sept 78 AL-7738-L
K. Viscosity, cSt						
at 40°C	62.2	56.6	60.4	64.6	70.1	59.8
at 100°C	9.8	9.1	9.4	9.6	9.8	9.0
VI	141	141	136	129	121	128
TAN	1.72	2.09	2.65	2.56	3.10	6.06
TBN	5.14	4.66	3.65	4.54	6.04	4.00
Flash Point, °C	224	224	215	218	177	193
Pentane Insol., wt% (w/coag)	0.07	0.32	0.53	0.60	0.23	0.20
Benzene Insol, wt% (w/coag)	0.05	0.25	0.31	0.44	0.16	0.17
Metals, ppm						
AA						
Fe	40	75	56	64	61	59
Pb	1484	2361	1890	1835	1545	1502
Cu	<1	3	3	3	3	3
Sn	<3	<1	<1	<5	<5	<5
Cr	<1	2	2	3	2	2
Si	<1	12	<1	13	<5	<5
Al	3	8	4	5	6	<5
Mileage	891	440	899	873	743	594
Mobile Test Kits						
Dielectric Cons. Kit H	-1.5	0.1	1.8	2.5	3.1	3.1
Acidity Kit A	Blue	Blue	Blue	Blue	Blue	Blue
Vis Comp. Kit A	4.0	3.6	5.0	5.0	5.4	4.0

TABLE B-21. FT. SAM HOUSTON FLEET TEST USING MIL-L-46152 10W/30 (1972 Chevrolet Pickup - G125)

Properties	28 Mar 78 AL-7365-L	26 Apr 78* AL-7402-L	31 May 78 AL-7465-L	6 July 78 AL-7613-L	9 Aug 78 AL-7674-L	14 Sept 78 AL-7739-L
K. Viscosity, cSt						
at 40°C	63.2	54.4	55.7	57.1	54.2	50.2
at 100°C	9.7	8.94	8.9	9.0	8.6	8.2
VI	136	143	138	135	134	135
TAN	2.96	1.82	2.30	2.74	3.20	6.88
TBN	4.66	4.93	4.10	2.36	3.83	2.14
Flash Point, °C	218	210	204	213	185	196
Pentane Insol, wt% (w/coag)	2.59	0.06	0.11	0.72	0.82	1.44
Benzene Insol, wt% (w/coag)	1.21	0.04	0.04	0.37	0.49	0.45
Metals, ppm						
AA						
Fe	141	25	31	51	75	92
Pb	432	101	157	1018	1000	1291
Cu	3	<1	2	1	2	2
Sn	<3	<1	<1	<1	<5	<5
Cr	4	<1	1	2	2	3
Si	<1	<1	<1	9	<5	<5
Al	<5	<5	2	<1	<5	<5
Mileage	325	347	544	639	674	345
Mobile Test Kits						
Dielectric Cons. Kit H	4.3	-1.2	1.6	2.0	2.5	2.7
Acidity Kit A	Blue	Blue	Blue	Blue	Blue	Green
Vis Comp. Kit A	4.4	3.0	3.5	3.4	3.0	2.9

* Oil was drained on 25 Apr 1978

TABLE B-22. FT. SAM HOUSTON FLEET TEST USING
MIL-L-46152 10W/30
(1974 Chevrolet Pickup - G429)

Property	28 Mar 78 AL-7366-L	26 Apr 78 AL-7403-L	31 May 78 AL-7466-L	6 July 78 AL-7614-L	9 Aug 78 AL-7675-L	14 Sept 78* AL-7740-L
K. Viscosity, cSt						
at 40°C	63.4	63.9	67.8	67.3	70.4	65.3
at 100°C	9.7	9.7	10.1	10.1	10.7	10.0
VI	135	133	133	135	141	137
TAN	2.51	2.93	3.59	3.46	3.89	4.65
TBN	7.51	8.24	5.84	6.28	7.14	7.24
Flash Point, °C	232	429	221	218	204	216
Pentane Insol, wt% (w/coag)	0.09	0.05	0.06	0.13	0.17	0.02
Benzene Insol, wt% (w/coag)	0.04	0.04	0.05	0.06	0.10	0.01
Metals, ppm						
AA						
Fe	35	46	42	58	70	19
Pb	2425	2581	2132	2346	2295	970
Cu	1	<1	2	2	2	1
Sn	<3	<1	<1	<1	<5	<5
Cr	4	6	9	10	12	2
Si	<1	4	<1	5	<5	<5
Al	<3	<5	4	5	5	<5
Mileage	336	412	478	402	442	394
Mobile Test Kits						
Dielectric Cons. Kit H	1.5	1.5	2.2	2.3	2.6	2.2
Acidity Kit A	Blue	Blue	Blue	Blue	Blue	Blue
Vis Comp. Kit A	4.6	4.9	5.8	5.2	5.2	5.0

*Oil was drained 31 Aug 1978.

TABLE B-23. FT. SAM HOUSTON FLEET TEST USING MIL-L-46152 10W/30 AND GRADE 30 OR 20W/40 (1974 Chevrolet Pickup - G435)

Property	28 Mar 78	26 Apr 78 AL-7412-L	31 May 78 AL-7467-L	6 July 78	9 Aug 78 AL-7676-L	14 Sept 78* AL-7741-L
K. Viscosity, cSt						
at 40°C		69.7	77.9		76.9	122.7
at 100°C		10.2	11.3		10.5	13.5
VI		131	135		122	105
TAN		3.39	3.18		3.50	4.53
TBN		7.52	6.06		8.30	6.49
Flash Point, °C		199	207		204	227
Pentane Insol, wt% (w/coag)		0.05	0.10		0.14	0.04
Benzene Insol, wt% (w/coag)		0.04	0.08		0.06	0.02
Metals, ppm				On TDY, not sampled.		
AA						
Fe		26	25		32	14
Pb		54	45		58	31
Cu		<1	2		2	1
Sn		<1	<1		<5	<5
Cr		<1	2		1	<1
Si		8	<1		<5	<5
Al		<5	4		<5	<5
Mileage		703	738		1224	650
Mobile Test Kits						
Dielectric Cons. Kit H		1.7	2.7		3.3	2.3
Acidity Kit A		Blue	Blue		Blue	Blue
Vis Comp. Kit A		4.8	6.2		5.8	8.2(2.5)**

* Oil was drained 21 Aug 1978.
** The numbers in parentheses used OE/HDO-30 as baseline.

TABLE B-24. FT. SAM HOUSTON FLEET TEST USING
MIL-L-46152 10W/30
(1974 Chevrolet Pickup - G437)

Property	28 Mar 78 AL-7367-L	26 Apr 78 AL-7405-L	31 May 78* AL-7468-L	6 July 78 AL-7615-L	9 Aug 78 AL-7677-L	14 Sept 78 AL-7742-L
K. Viscosity, cSt						
at 40°C	79.9	66.8	69.7	80.2	80.0	76.9
at 100°C	10.9	9.8	10.1	10.7	10.6	10.4
VI	123	129	129	118	117	120
TAN	2.90	3.46	3.06	2.54	2.89	5.88
TBN	6.09	8.00	4.58	3.89	6.59	5.62
Flash Point, °C	232	238	238	240	218	213
Pentane Insol, wt% (w/coag)	0.92	0.15	0.09	0.05	0.09	0.09
Benzene Insol, wt% (w/coag)	0.54	0.10	0.09	0.11	0.07	0.06
Metals, ppm						
AA						
Fe	34	46	17	26	26	33
Pb	123	101	41	63	58	73
Cu	3	3	2	2	2	2
Sn	< 3	10	< 1	< 1	< 5	< 5
Cr	2	2	1	1	1	2
Si	< 1	12	< 1	6	< 5	< 5
Al	10	13	8	9	10	11
Mileage	798	647	838	748	557	640
Mobile Test Kits						
Dielectric Cons. Kit H	3.2	2.9	1.8	2.6	2.9	3.0
Acidity Kit A	Blue	Blue	Blue	Blue	Blue	Blue
Vis Comp. Kit A	6.2	6.4	6.6	6.2	6.0	6.1

* Oil was drained on 2 May 1978.

TABLE B-25. 1978 HONDA ACCORD (CVCC ENGINE)
MIL-L-2104C OE/HDO-30

Property	Miles					
	NEW	12,000	15,000	18,000	21,000	24,000
K. Viscosity, cSt						
at 40°C	106.6	107.5	107.6	108.1	107.9	108.5
at 100°C	11.6	11.9	12.0	12.1	11.9	12.2
VI	98	101	102	102	100	104
TAN	2.3	2.11	2.54	2.96	3.69	4.54
TBN	13.9	12.9	13.2	13.8	14.2	14.3
Flash Point, °C	223	220	227	230	228	234
Pentane Insol, wt% (w/coag)	0.04	0.11	0.32	0.50	1.45	2.07
Benzene Insol, wt% (w/coag)	0.03	0.08	0.17	0.41	0.71	0.98
Metals, ppm						
AA						
Fe	---	16	22	30	41	50
Pb	---	79*	340	1391	5210	7700
Cu	---	<1	2	5	7	8
Sn	---	<1	<5	<5	<5	<5
Cr	---	<1	2	4	5	8
Si	---	<1	<5	<5	<5	<5
Al	---					6
Mobile Test Kits						
Dielectric Cons. Kit H	0	1.7	2.1	2.2	2.3	4.0
Acidity Kit A	Blue	Blue	Blue	Blue	Blue	Blue
Vis Comp. Kit A	0	0.8	1.1	1.3	1.6	2.0

* Used leaded gasoline

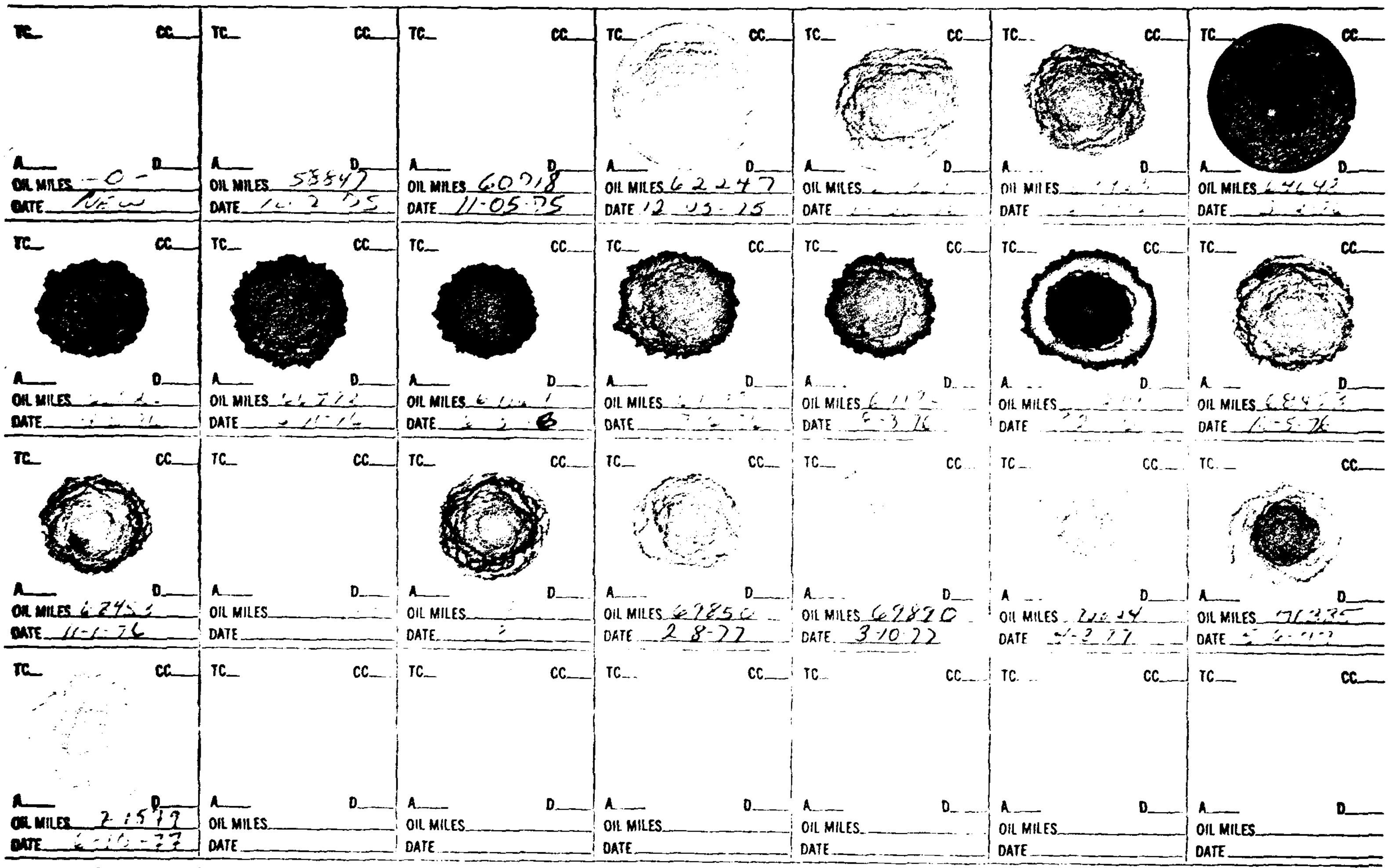
TABLE B-26. 1978 FORD 150-4x4 PICKUP (400 CID)
MIL-L-46152-L Grade 30

Property	Miles NEW	2000	4000	6000	7500
K. Viscosity, cSt					
at 40°C	108.5	110.7	112.9	113.2	132.5
at 100°C	12.2	12.9	13.5	13.9	15.7
VI	103	110	117	122	124
TAN	1.95	2.19	2.43	3.01	8.86
TBN	5.62	5.47	5.13	4.62	4.51
Flash Point, °C	246	242	240	233	175
Pentane Insol, wt% (w/coag)	0.015	0.4	0.5	1.7	6.92
Benzene Insol, wt% (w/coag)	0.01	0.3	0.5	1.3	3.20
Metals, ppm					
AA					
Fe	---	8	34	102	250
Pb	---	43	1376*	9743	19,994
Cu	---	<1	2	11	59
Sn	---	<1	<5	12	33
Cr	---	<1	1	7	12
Si	---	<5	<5	12	59
Al	---	<3	<5	7	15
Mobile Test Kits					
Dielectric Cons. Kit H	0	1.0	1.7	2.6	4.7
Acidity Kit A	Blue	Blue	Blue	Blue	Green/Yellow
Vis Comp. Kit A	0	0.6	1.2	1.5	2.6

* Used leaded gasoline

FIGURE B-1. OILPRINT ANALYSIS - VEHICLE NO. 890

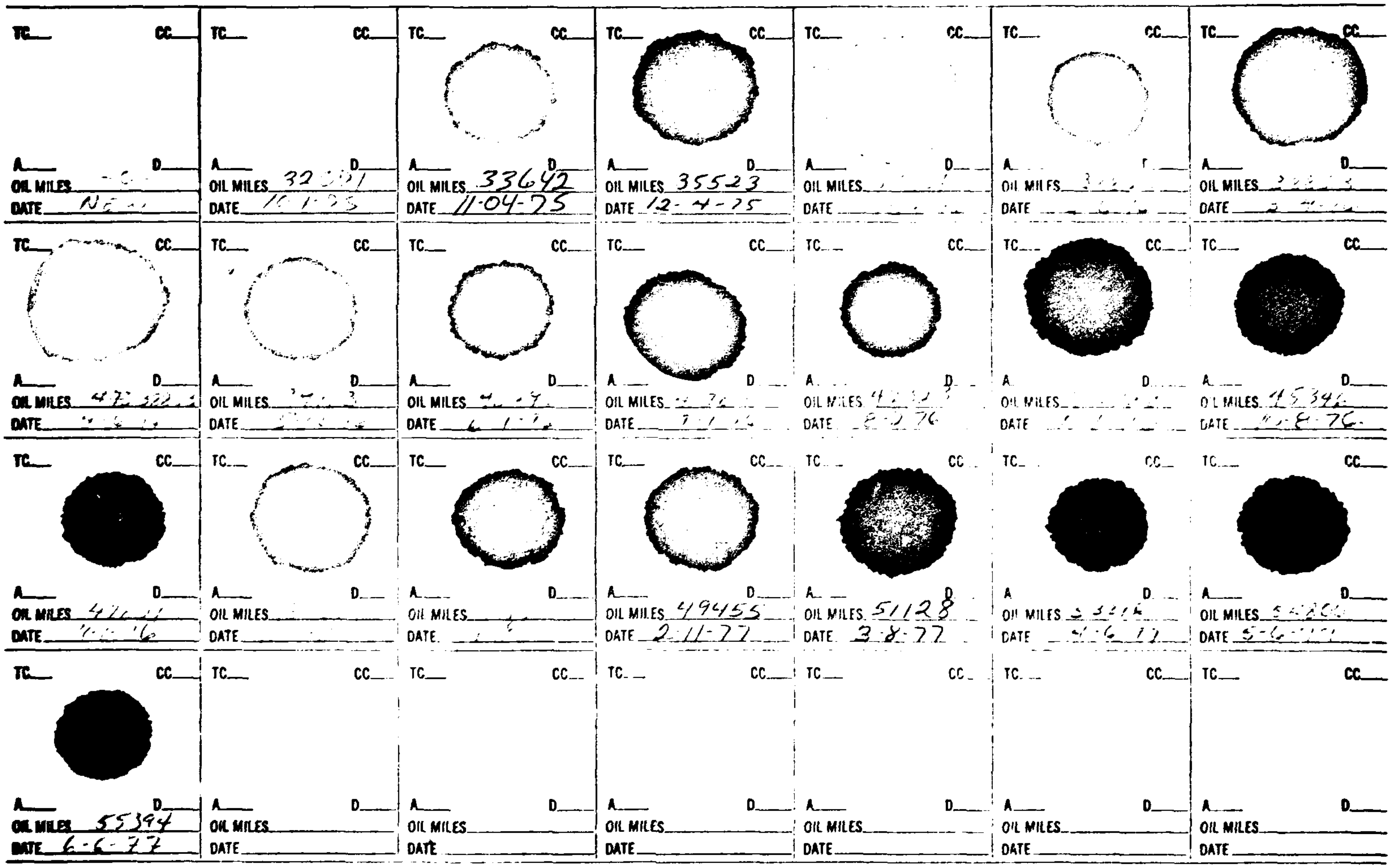
Total Miles at Start Test: 57690 Vehicle: 1969 12-Passenger Checker Bus



Oil Condition Legend | A-ALKALINITY, G-Good, F-Fair, P-Poor | D-DISPERSANCY, G-Good, F-Fair, P-Poor | TC-TOTAL CONTAMINANTS, L-Light, M-Medium, H-Heavy | CC-COOLING CONTAMINANTS, W-Water, Gl-Glycol |

FIGURE B-2. OILPRINT ANALYSIS - VEHICLE NO. 891

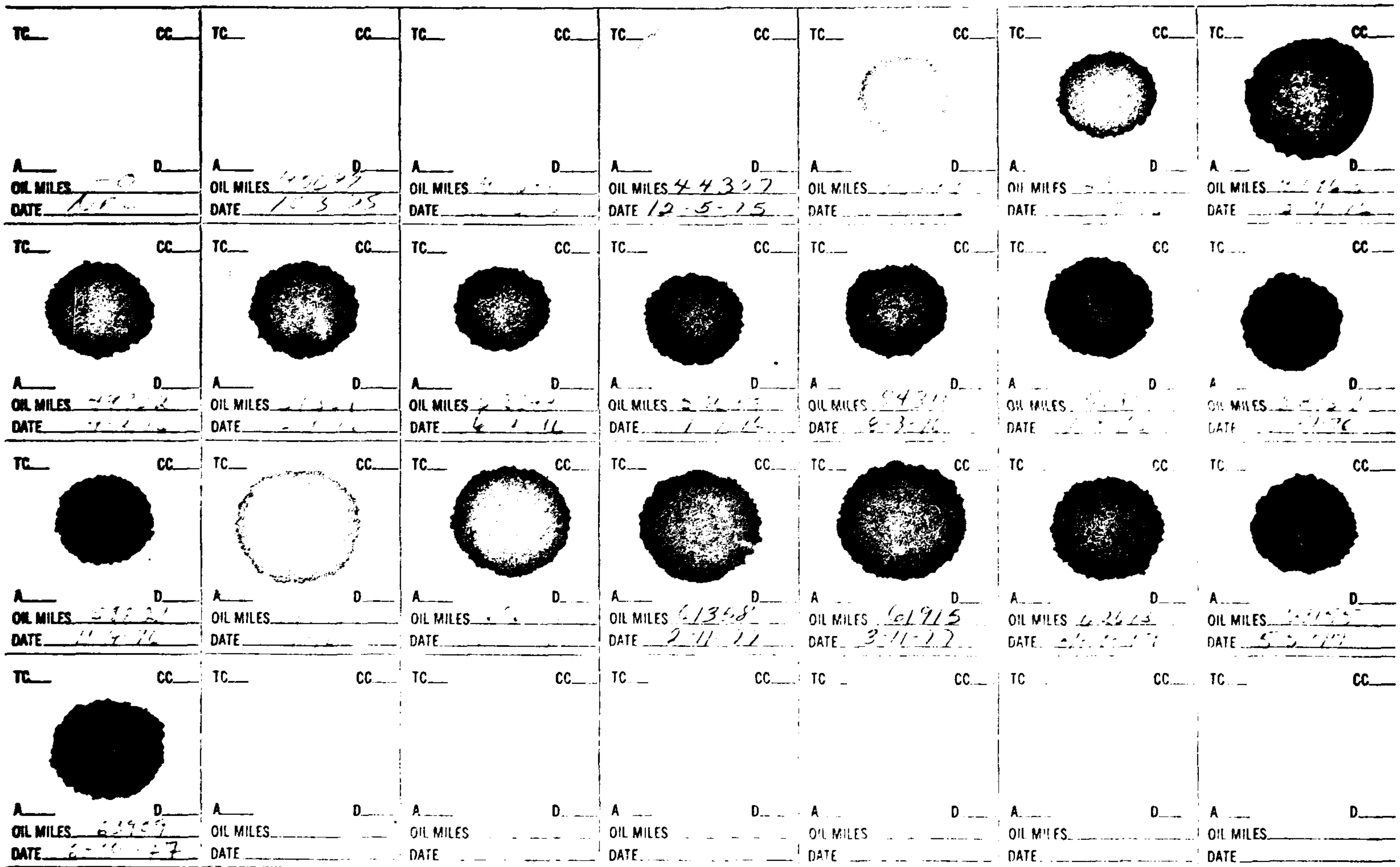
Total Miles at Start Test: 29865 Vehicle: 1973 12-Passenger Checker Bus



Oil Condition Legend | A-ALKALINITY, G-Good, F-Fair, P-Poor | D-DISPERSANCY, G-Good, F-Fair, P-Poor | TC-TOTAL CONTAMINANTS, L-Light, M-Medium, H-Heavy | CC-COOLING CONTAMINANTS, W-Water, Gl-Glycol |

FIGURE B-3. OILPRINT ANALYSIS - VEHICLE NO. 289

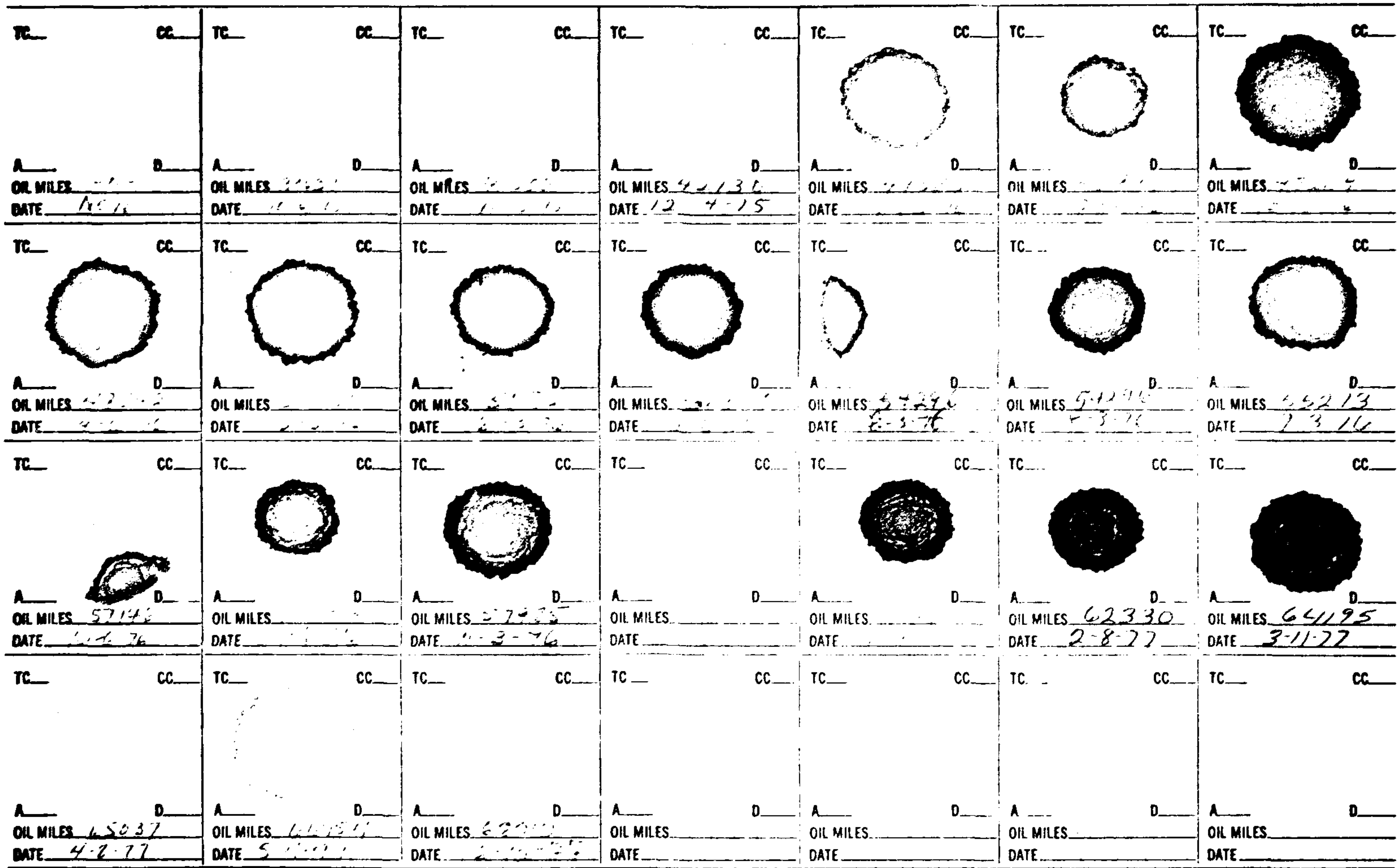
Total Miles at Start Test: 33860 Vehicle: 1973 Chevrolet Station Wagon



Oil Condition Legend | A ALKALINITY, G-Good, F-Fair, P-Poor | D DISPERSANCY, G-Good, F-Fair, P-Poor | TC-TOTAL CONTAMINANTS, L-Light, M-Medium, H-Heavy | CC-COOLING CONTAMINANTS, W-Water, Gl-Glycol |

FIGURE B-4. OILPRINT ANALYSIS - VEHICLE NO. 291

Total Miles at Start Test: 37603 Vehicle: 1973 Chevrolet Station Wagon



Oil Condition Legend | A-ALKALINITY, G-Good, F-Fair, P-Poor | D-DISPERSANCY, G-Good, F-Fair, P-Poor | TC-TOTAL CONTAMINANTS, L-Light, M-Medium, H-Heavy | CC-COOLING CONTAMINANTS, W-Water, Gl-Glycol |

APPENDIX C

PREVIOUS TEST RESULTS

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FEASIBILITY OF FIELD TEST KITS FOR ASSESSING IN-SERVICE CONDITI--ETC(U)
MAR 79 H W MARBACH, S J LESTZ, M E LEPERA   DAAG53-76-C-0003

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APPENDIX C

PREVIOUS TEST RESULTS

Vehicle No.	Oil Type	K. Viscosity, cSt at 100°F	K. Viscosity, cSt at 210°F	Neut. No. TAN	Neut. No. TBN	Pentane Insol., wt%	Membrane Filter, wt%	Crankcase Dilution, vol%	Kit E Rating	Kit D Ratings* Contam.	Kit D Ratings* Acidity	Kit D Ratings* Dilution
(New)	MIL-L-2104B	125.5	12.16	1.31	0.23	0	0	0	---	---	---	---
A	MIL-L-2104B	104.8	12.13	4.33	0.57	4.29	0.18	1.2	7.5	M	Green	>5
A	MIL-L-2104B	169.3	14.31	3.58	0	7.45	4.55	2.8	19.0	H	Green	>5
A	MIL-L-2104B	104.1	12.78	4.02	0.02	4.76	1.95	3.2	17.5	H	Gr/Yellow	>5
A	MIL-L-2104B	142.5	15.44	6.10	0	5.43	5.29	0.8	17.5	H	Gr/Yellow	>5
B	MIL-L-2104B	74.0	8.75	6.17	0.44	4.77	0.58	2.0	7.5	M	Green	5
C	MIL-L-2104B	89.9	10.54	2.51	0.55	2.43	0.55	0.8	3.0	M	Blue	>5
C	MIL-L-2104B	91.2	9.94	2.44	0.97	0.65	0.34	3.0	0.5	L	Blue	5
C	MIL-L-2104B	88.8	10.16	2.50	0.63	1.49	0.60	2.1	2.0	L/M	Blue	5
D	MIL-L-2104B	116.7	11.99	12.05	0.30	3.96	0.41	1.2	7.5	L/M	Green	>5
D	MIL-L-2104B	90.0	11.01	3.56	0.52	4.77	0.40	2.2	6.0	M	Blue	5
E	MIL-L-2104B	96.4	10.83	4.23	0.20	4.05	0.39	2.6	5.0	L/M	Green	>5
E	MIL-L-2104B	107.4	11.54	3.57	0.47	3.62	0.26	2.5	5.0	M	Blue/Gr	>5
E	MIL-L-2104B	79.3	9.05	1.72	0.35	0.47	0.58	2.1	7.0	L/M	Blue	>5
	MIL-L-2104B	111.3	11.63	1.05	0.49	3.96	0.27	1.0	6.0	L/M	Blue	>5
(New)	MIL-L-9000F	121.9	12.19	1.29	0.90	0	0	0	---	---	---	---
	MIL-L-9000F	92.5	10.22	2.01	0.43	0.85	0.61	0.8	3.0	L/M	Green	>5
	MIL-L-9000F	23.7	4.66	1.38	0.66	0.53	0.74	12.5	5.0	M/H	Blue	>5
H	MIL-L-9000F	145.6	13.95	4.85	0	0.92	0.10	0.8	14.5	L/M	Green	>5
H	MIL-L-9000F	134.6	12.57	5.62	0	4.28	0.83	2.1	21.0	H	Gr/Yellow	>5
I	MIL-L-9000F	119.1	11.99	2.78	0.30	0.50	0.19	0.7	6.0	L/M	Blue	>5
I	MIL-L-9000F	117.0	12.11	2.33	0.36	0.24	0.20	1.0	3.0	L/M	Blue/Gr	>5
J	MIL-L-9000F	55.6	7.83	1.77	0.10	0.72	0.40	1.7	10.5	L/M	Green	5
K	MIL-L-9000F	100.4	10.95	3.70	0.70	1.45	0.87	1.0	4.0	M	Blue	>5

* The following abbreviations apply to the "Contaminant" and "Acidity" ratings:

L - Satisfactory — Blue - Neutral
M - Borderline — Green - Borderline
H - Unsatisfactory — Yellow - Acid

APPENDIX C (cont.)

PREVIOUS TEST RESULTS

Vehicle No.	Oil Type	K. Viscosity, cSt at 100°F	K. Viscosity, cSt at 210°F	Neut. No. TAN	Neut. No. TBN	Pentane Insol., wt%	Membrane Filter, wt%	Crankcase Dilution, vol%	Kit E Rating	Kit D Ratings* Contam.	Kit D Ratings* Acidity	Kit D Ratings* Dilution
(New)	SAE 10W-30	78.1	12.74	4.80	3.40	0	0	0	---	---	---	---
L	SAE 10W-30	87.2	10.91	3.21	0.64	2.58	1.05	2.8	10.5	M/H	Blue	< 5
L	SAE 10W-30	93.1	11.18	7.84	1.30	7.29	0.70	0.8	9.5	H	Blue	< 5
L	SAE 10W-30	165.9	10.37	7.68	1.69	7.77	0.25	1.1	13.0	M	Blue	< 5
L	SAE 10W-30	79.4	11.31	7.86	0.68	3.33	0.33	2.7	15.0	M/H	Green	< 5
M	SAE 10W-30	69.9	10.51	11.09	1.30	6.74	0.51	1.1	8.5	L/M	Blue	< 5
M	SAE 10W-30	67.7	9.84	0.85	1.42	5.55	0.51	1.2	7.0	M	Blue	< 5
M	SAE 10W-30	70.4	10.33	11.47	0.88	6.05	0.35	1.2	10.0	M	Blue	< 5
N	SAE 10W-30	90.0	24.47	12.98	0.11	15.70	8.80	2.6	26.0	M/H	Yellow	< 5
O	SAE 10W-30	58.0	9.74	7.60	3.20	2.96	0.08	2.0	5.5	L	Blue	5
O	SAE 10W-30	56.2	9.78	7.01	2.62	3.19	0.16	1.5	5.5	L	Blue	5
O	SAE 10W-30	60.1	9.76	8.47	1.15	5.72	1.86	1.9	9.5	L/M	Blue	5
P	SAE 10W-30	63.0	10.04	10.23	2.03	4.71	0.42	1.2	9.5	L/M	Blue	5
P	SAE 10W-30	61.9	9.37	10.69	1.17	8.56	0.43	2.2	14.0	M/H	Green	5
Q	SAE 10W-30	60.9	9.64	6.88	2.62	5.25	0.39	1.1	7.0	L/M	Blue	5

* The following abbreviations apply to the "Contaminant" and "Acidity" ratings:

L - Satisfactory; Blue - Neutral
M - Borderline; Green - Borderline
H - Unsatisfactory; Yellow - Acid

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